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EMISSION SAMPLE PROBE INVESTIGATION OF A MIXED FLOW TF30 TURBOF--ETC(U)
NOV 78 G R SLUSHER

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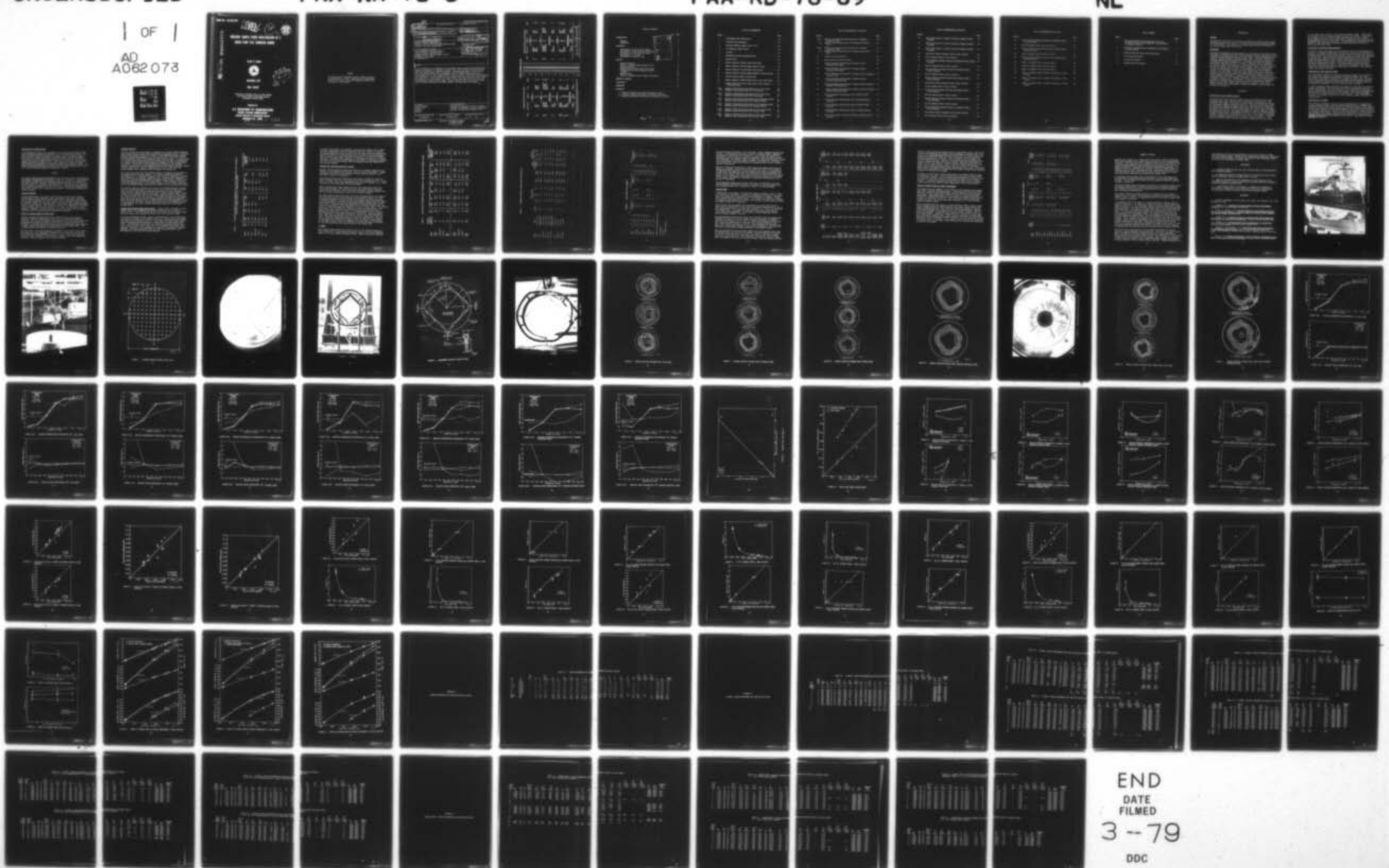

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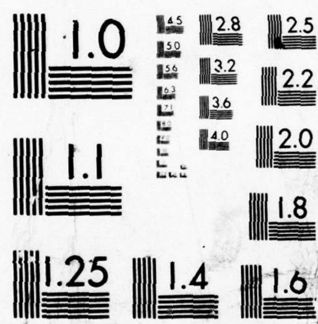

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EMISSION SAMPLE PROBE INVESTIGATION OF A MIXED FLOW TF30 TURBOFAN ENGINE

Gerald R. Slusher

DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

NOVEMBER 1978

FINAL REPORT

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16. Abstract

An investigation of the emissions in the exhaust plume of mixed-flow TF30 turbofan engine was conducted to optimize the shape, size, and location of fixed probes for acquiring representative emission samples. Traverse measurements of 121 points over the exhaust nozzle were accomplished with the sample points located on a 2-inch-square grid. The average emission levels, contours, and profile distributions were determined. Exhaust emissions were measured with four mixing multihole averaging probes in the core exhaust, the engine turbine discharge pressure probes, and an experimental diamond probe design. Results indicate that the 12-point diamond probe provides representative exhaust samples from mixed-flow TF30 engine.

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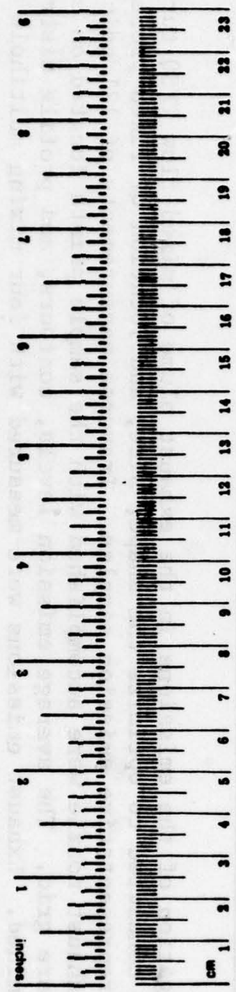
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

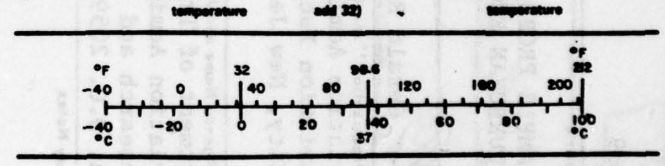
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

The purpose of this report is to define variability in aircraft turbine engine emission measurements as related to acquiring representative emission samples with fixed probes. The results of an exhaust emission probe investigation of the TF30 turbofan engine are reported.

BACKGROUND.

The Clean Air Amendments of 1970 (reference 1) specified that the United States Department of Transportation (DOT) and the Federal Aviation Administration (FAA) promulgate regulations enforcing the aircraft engine emission standards established by the Environmental Protection Agency (EPA). Two major variability problems regarding emission measurements have been identified by industry and Government study teams (reference 2). One problem area affecting emission measurements involved the effect of changes in ambient weather conditions, particularly temperature and humidity, on emission levels. The second problem involved acquiring a representative emission sample from the exhaust plume. The FAA was commissioned to conduct an investigation of these variability problems at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey. From this study, ambient temperature and humidity correction factors were developed for exhaust emissions from two classes of turbine engines (reference 3). Studies of the traverse emission plots indicated that the use of fixed probing techniques to provide representative samples is feasible (reference 4). The results of that portion of the investigation designed to optimize probing techniques to acquire representative emission samples from the TF30 turbine engine exhaust is presented in this report. Emission sample probe investigation of mixed-flow JT8D-11 turbofan engine can be found in reference 5.

DISCUSSION

DESCRIPTION OF TF30 TURBOFAN ENGINE.

A surplus United States Air Force (USAF) mixed-flow TF30-P1 turbofan engine was selected as a test vehicle because of performance similarities to the commercial JT8D engine. The TF30-P1 turbofan engine was modified by removing the afterburner assembly including spray bars, fuel manifold and flame holder, and installing a fixed-area exhaust nozzle for commercial engine simulation. The engine, as modified, provided 11,800 pounds (lb) thrust, had a compressor pressure ratio of 17.0 to 1, and featured eight-can annular combustion chambers and duplex fuel nozzles. The engine incorporates a front fan having a bypass-to-engine airflow ratio of approximately 1.09 to 1, with the fan air diverted through an annular duct that forms the outer shell of the engine. The bypass air duct terminates downstream of the turbine discharge (station 7). The bypass fan airflow forms a circular envelope of relatively cool air around

the core exhaust gas stream in the tailpipe and exhaust nozzle. Three struts are utilized in the core engine exhaust to support the turbine. Installation of the engine for test on a thrust measuring stand may be seen in figure 1. Engine operation was essentially under free-air conditions as the inlet air and the exhaust gases were not restricted. Test equipment and instrumentation were typical of that required for experimental engine performance testing on a static sea level test stand.

DESCRIPTION OF TRAVERSE PROBE MECHANISM.

A detailed traverse investigation of the exhaust plume of the TF30 engine was necessary to establish actual emission levels and to generate the data base for preparing the emission contours and profiles required for design and evaluation of fixed probes. The traverse probe mechanism shown in figure 2 was constructed to position the single point sample probe remotely within a vertical plane behind the engine exhaust nozzle. Emission measurements were recorded on a 2-inch grid located in the vertical plane at an axial distance of 2 inches behind the engine exhaust nozzle. The traverse sample grid consisting of 121 points is depicted in figure 3. Emissions were measured at the points identified in the traverse grid and engine power conditions of idle, approach, cruise, and maximum continuous.

DESCRIPTION OF CORE SAMPLING PROBES.

Four fixed sample probes were installed through the tailpipe at the core-fan duct splitter for sampling the undiluted core exhaust gases. Each probe incorporated three sample orifices with a diameter of 0.030 inch. The purpose of the core probes was to establish and maintain reference emission measurements to which all subsequent probing test results at the exhaust nozzle may be compared and evaluated. The core probes are shown in figure 4.

A random integrating sampling pattern was achieved by installing the probes on varying chord angles. The chord angles and probe locations were selected to include sampling behind the bearing support struts where high concentration of hydrocarbons had been reported for other engines. Emissions were sampled from the core probes through an externally heated manifold. These probes were utilized as a constant reference for all the candidate probes throughout the investigations.

DESCRIPTION OF T PROBES.

Four probes in the shape of the letter T were fabricated to be adjustable for variable immersion depth to explore sample depth design for a diamond probe. Each probe featured three sample points of 0.030-inch diameter. Three sampling orifices were located in the horizontal member of the T probe with an orifice in the center separated by orifices in both directions by 1.4 inches (one-ninth the exhaust nozzle radius). The four probes were installed on the 45° radii in each quadrant of the exhaust nozzle and were manifolded to provide emission samples representative of the average of four probes. The installed T probes are shown in figure 5.

DESCRIPTION OF DIAMOND PROBE.

An experimental 12-point probe recommended for representative emission sampling of mixed-flow engines in reference 6 was also installed and tested. The probe was fabricated in the shape of a square to clear the exhaust centerbody common on a number of aircraft installed engines, and was referred to in this report as the diamond probe because it was rotated 45° for emission sampling as shown in figures 6 and 7. Each side of the square contains three sample ports with the orifice in the center separated by orifices in both directions by approximately 1.42 inches (one-ninth exhaust nozzle radius). The center orifices were located at 62 percent of the nozzle radius at 45°, 135°, 225°, and 315° which is referred to as the 45° location.

RESULTS

The nozzle traverse emission measurements and other test results concerning the TF30 engine investigation are reported, in part, in reference 7. These emission measurements together with the remaining probe test results are included in this report and are corrected to standard ambient temperature of 59° F and zero specific humidity in accordance with reference 3. These emission measurements are included in appendices A, B, and C for further analysis and comparison with other probe results, and to develop probe designs for acquiring representative emission samples.

TRAVERSE CONTOURS.

Traverse measurements (121 points) were acquired at engine power settings corresponding to idle, approach, cruise, and maximum continuous. Emission maps of carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbons (THC), and nitrogen oxides (NO_x) in units of parts per million (ppm) volume are shown in figures 8 through 11. Maps are shown for each gas having significant magnitudes at a power setting. The contours are shown to be influenced by the three turbine bearing support struts located at 60°, 180°, and 300° and the eight combustion chambers. The wide variation in pollutant concentration, the steep gradients, and the resulting probing problems are apparent.

EFFECT OF TURBINE BEARING SUPPORT STRUT.

Traverse testing was conducted with the engine modified to incorporate an additional turbine bearing support strut in the core exhaust as shown in figure 12. The strut was located at approximately 135°. This modification was accomplished to evaluate the effect of the strut on emission patterns and gradients. Standard traverses for gaseous emission measurements were completed at engine power conditions of idle and maximum continuous power (MCP). The traverse contours are depicted in figures 13 and 14.

The effect was to move the emissions in proximity of the strut outward toward the nozzle lip. The measurements indicated that concentrations of the gas moved outward from approximately 0.5 inch to 1 inch. Under high engine power conditions, some transfer or centrifuging of emissions out to the nozzle lip occurred. The strut appears to act or aid in mixing.

TRAVERSE PROFILES.

Traverse profiles were established by averaging four traverse emission measurements acquired from constant radius positions each separated by 90°. Additional points were averaged by varying the radius or corresponding immersion depths. Traverse emission measurements on the four radii at 45°, 135°, 225°, and 315° were averaged for each of five immersion depths along the radii. A second group of traverse emission measurements located along the four radii coinciding with the vertical and horizontal centerlines were averaged for each of seven immersion depths. Ratios were then established by dividing the four averaged emission concentrations at each immersion depth by the overall 121-point traverse average concentration. Ratios of emissions at 45° and at 90° were then plotted against their immersion depth on figures 15a through 22a.

The profile plots show the steep emission slopes or gradients in the exhaust of the mixed-flow TF30 turbofan engine. At low power, maximum gradients are approximately 45- to 50-percent change per inch, while at high power the slopes are on the order of 40-percent change per inch. Gradients were estimated in the areas of traverse averages where the emission ratio is one. Trends can be formed regarding the fixed probing requirements. Profile emission concentrations were representative of the traverse average on the 45° radii location at 62.3 to 63.4 percent radius and on the 90° radii at 64.3 to 64.7 percent radius.

The emission index was calculated for each of the averaged emission concentrations at each emersion depth on the 45° radii and for the 90° radii as previously described. Ratios were established by dividing the three emission indices at each immersion depth by the overall traverse average index. Ratios of emission indices were then plotted against immersion depth in figures 15b, 16b, 17b, 18b, 19b, 20b, 21b, and 22b . The profile illustrations of emission index ratio show that the rate of emission change with respect to immersion depth has become essentially zero at immersion depths of approximately 4.5 inch to the center of the plume. The emission indices located at immersion depths of approximately 4.5 inch and deeper essentially agree with the traverse average index.

DIAMOND AND CRUCIFORM PROBE CALCULATIONS. A square probe, referred to as the diamond probe, was recommended by the FAA (reference 6) and is shown in figures 6 and 7. The probe design sampled at 62 percent of the nozzle radius, with the center points located on the 45°, 135°, 225°, and 315° radii.

Calculated performance results, based on interpolations of the traverse maps and related in percent of the traverse average on a concentration and emission index basis, are tabulated in table 1. The diamond probe will provide representative emission concentrations and indices under all engine power conditions. Also included are measurement or sample efficiencies defined as the ratio of carbon balance fuel-to-air ratio to the measured fuel-to-air ratio expressed in percent. This parameter is a measure of representative emission sampling. The calculated sample efficiency was considered equal to the efficiencies of the 121-point traverse average.

TABLE 1. CALCULATED DIAMOND PROBE PERFORMANCE—12 POINTS INTERPOLATED FROM TRAVERSE MAPS—62 PERCENT RADIUS—45° ANGULAR POSITION

		Percent Traverse Concentration				Percent Traverse EI			Sample Efficiency
Mode	Run No.	CO_2	CO	THC	NO_x	CO	THC	NO_x	$\frac{F/A_{CB}}{F/A_M}$ X100 (%)
Idle	14	101.2	98.2	98.0	-	97.1	98.0	-	93.7
Idle	264	98.0	98.1	99.9	-	100.1	101.9	100.9	104.9
Approach	15	102.9	101.4	92.6	-	98.6	90.4	-	98.6
Cruise	16	102.6	95.0	-	102.9	92.8	97.8	102.9	74.5
MCP	17	99.5	-	-	101.5	97.5	-	101.5	89.1
MCP	266	99.7	-	-	99.8	100.3	-	100.1	90.7

To predict and evaluate area weighted cruciform probe designs, the traverse volumetric measurements existing along the two sets of radii (45° and 90°) were area weighted in relation to the point from which they were acquired and the emission index (EI) was calculated from the carbon balance relationship. Table 2 contains the results including the percent of the traverse average. When all of the points (16) along the 45° radii were utilized in the analysis, calculated cruciform probe performance was poor based on volumetric concentrations but was excellent, however, when the emission index was compared with the traverse average.

TRAVERSE AND CORE PROBE EMISSION INDICES.

Average traverse emission indices were corrected for ambient temperature and humidity in accordance with reference 3 and are tabulated in table 3. Engine performance with observed and corrected traverse and core probe EI's are included in table A-1 of appendix A.

The pollutant EI from the traverse and core probes is plotted in figure 23. Under the engine idle mode, the average EI for two traverses were, 47.7 for CO, 10.9 for the THC, and at the maximum continuous, NO_x EI averaged 13.46. These levels are for the high smoke T30 turbofan engine.

Under the engine idle mode, samples from the core probes were higher than the traverse average. THC EI and CO EI were 13.6 percent and 8.0 percent higher than the traverse. Above idle power conditions, emission sampled from the core probes were generally closer to the traverse average.

The carbon balance (CB) fuel-to-air (F/A) ratio is compared with the measured (M) fuel-to-air ratio for the traverse and core probes in figure 24. This relationship emphasizes the CO_2 content of the samples and is an indication of sample efficiency. Traverses at idle and approach engine modes were nearly ideal, approaching a one-to-one relationship between the F/A_{CB} ratio and the M F/A ratio. Traverses under high engine power conditions deviated from the ideal F/A relationship and were believed to be low in CO_2 or lean. The undiluted high CO_2 in the core exhaust is reflected in the core probe results. Core probe results were evaluated by equivalent dilution calculations using a nominal fan bypass ratio of 1.09 to 1. Core measurements at the cruise and MCP modes were near ideal when calculated on this basis. Under low engine power conditions, the calculations indicate that the core probe samples are rich. The actual measurements from the core probes confirm this. The core probes installed through the tailpipe on chords to sample only the primary or core gases were utilized as a reference for all testing. These results are included in table 4 with the complete core probe data base. Performance of the core probes were poor, particularly at idle engine power.

T PROBES.

The T shaped sample probes were tested at each of four immersion depths: at axial location of 2 inches behind the exhaust nozzle, and at three immersion depths at 10 inches behind the exhaust nozzle. Engine testing was conducted

TABLE 2. CALCULATED CRUCIFORM PROBE PERFORMANCE--AREA WEIGHTED TRAVERSE POINTS

Mode	Angular Position (degrees)	Run No.	Percent Traverse Concentration CO_2	Percent Traverse Concentration CO	Percent Traverse Concentration THC	Percent Traverse Concentration NO_x	Percent Traverse EI CO	Percent Traverse EI THC	Percent Traverse EI NO_x	Sample Efficiency $\frac{F/A_{CB}}{F/A_M}$ X100 (%)
Idle	45	14	94.7	95.4	95.1	-	100.7	100.3	-	89.2
Idle	45	264	93.3	95.4	93.9	91.9	100.2	100.5	98.4	99.9
Approach	45	15	89.8	90.0	87.3	91.4	99.1	97.2	101.8	87.1
Cruise	45	16	95.9	92.8	78.3	104.0	92.1	81.8	100.9	71.0
MCP	45	17	86.4	89.5	-	87.6	103.4	-	101.4	79.0
MCP	45	266	91.8	92.5	-	89.2	100.7	-	97.1	83.9
Idle	90	14	94.6	92.1	93.3	-	97.4	98.8	-	88.9
Idle	90	264	103.8	101.4	99.4	105.4	97.8	95.9	101.7	110.9
Approach	90	15	93.6	98.8	107.9	96.8	105.4	115.2	103.4	90.9
Cruise	90	16	95.0	95.1	98.9	92.8	100.0	104.2	97.6	70.4
MCP	90	17	93.2	94.7	-	92.9	101.6	-	99.6	85.2
MCP	90	266	99.8	99.4	-	94.6	99.6	-	94.7	91.8

TABLE 3. TRAVERSE EMISSION INDICES AND EFFICIENCIES

Mode	Probe	Run No.	Emission Index lb/1000 lb Fuel CO	THC	NO$_x$	F/A$_M$	F/A$_{CB}$	Sample Efficiency F/A$_{CB}$x100/F/A$_M$ Percent	Corrected Emission Index lb/1000 lb Fuel CO	THC	NO$_x$
Idle	Nozzle Traverse	14	52.79	13.49	-	.00314	.00292	93.0	48.39	10.91	-
Idle	Nozzle Traverse (Extra strut)	264	54.67	15.66	2.66	.00325	.00356	109.5	47.12	10.90	3.57
Approach	Nozzle Traverse	15	15.75	1.78	5.00	.00432	.00413	95.6	13.62	0.93	6.26
Cruise	Nozzle Traverse	16	3.44	0.63	9.73	.00647	.0047	72.6	3.17	-	11.71
Max. Cont.	Nozzle Traverse	17	2.68	0.87	10.78	.00753	.0067	89.0	2.50	-	12.93
Max. Cont.	Nozzle Traverse (Extra strut)	266	3.66	0.46	10.94	.00759	.00686	90.4	2.78	-	13.99
Idle	Core Probe	14	57.06	15.32	2.49	.00314	.00888	135.3	52.30	12.39	3.08
Approach	Core Probe	15	15.56	1.50	5.09	.00432	.01052	116.5	13.46	0.83	6.37
Cruise	Core Probe	16	3.27	0.22	9.46	.00647	.01420	105.0	3.01	-	11.39
Max. Cont.	Core Probe	17	2.42	0.43	10.93	.00753	.01628	103.4	2.26	-	13.11

TABLE 4. CORE PROBE TEST RESULTS

		CO EI			THC EI			NO_x EI		
Code	N	$\overline{X}$	S	Percent Traverse Average	$\overline{X}$	S	Percent Traverse Average	$\overline{X}$	S	Percent Traverse Average
Idle	48	58.30	2.93	122.1	13.13	1.51	120.3	3.04	0.34	85.2
Approach	37	14.47	1.66	106.2	1.06	0.48	114.0	6.02	0.37	96.2
Cruise	45	3.35	0.45	97.4	-	-	-	11.14	1.14	95.1
MCP	44	2.39	0.18	90.5	-	-	-	13.56	0.66	100.7
Takeoff	20	2.06	0.16	-	-	-	-	15.49	1.01	-
*Idle	5	52.30	2.30	108.1	12.39	1.01	113.6	3.08	-	86.3
*Approach	4	13.45	1.35	98.8	0.83	0.30	89.2	6.37	0.23	101.8
*Cruise	3	3.01	-	95.0	-	-	-	11.39	-	97.3
*MCP	3	2.26	-	90.4	-	-	-	13.11	-	101.4

*NOTE: Recorded during the traverses.

N - Sample size

$\overline{X}$ - Mean

S - Standard Deviation

at the five power conditions of idle, approach, cruise, maximum continuous, and takeoff. The emission indices were corrected to standard ambient temperature and humidity in accordance with reference 3. The T probe test results are summarized in table 5 and are included in appendix B with the engine performance parameters. The emission ratio is defined as pollutant EI from the T probes to the pollutant EI from the traverse average. The ratios were established from corrected EI's and plotted against the immersion depth of the T probes in figures 25 through 34.

When the T probes were positioned 2 inches behind the exhaust nozzle and the engine at idle power, the CO and THC EI's agreed with the traverse average at an immersion depth equivalent to 68.6 percent of the radius. At maximum continuous power, the immersion depth for average NO_x EI was approximately 60.8 percent of the radius. With the T probes located 10 inches behind the exhaust nozzle, CO EI is estimated to agree with the traverse average at 63.9 percent of the radius, while NO_x EI is estimated to agree with the traverse at 66.3 percent of the radius.

The relationship between the F/A ratio from the CB calculations to the F/A ratios measured are plotted in figures 35 through 38. The F/A_{CB} agrees with the F/A measured when the T probes were located at 70-percent radius.

DIAMOND PROBE.

A fixed probe in the shape of a square was rotated to sample on the 45° radii at 62 percent of the radius. The probe, recommended by reference 6 was tested under five engine power conditions at axial locations of 2 inches, 7 inches, and 10 inches behind the exhaust nozzle. Test results are depicted in figures 39 through 62 and summarized in table 6, and tabulated in detail with the engine performance parameters in appendix C.

The F/A ratio from the emission CB calculations is plotted versus the F/A ratio from the measurements of fuel flow and airflow on figures 39, 46, and 53. The illustrations are for the three axial locations of 2, 7, and 10 inches for the diamond probe. The samples show greater F/A_{CB} ratios which indicate rich or high CO_2 measurements. As the probe is moved downstream, the F/A ratios CB become slightly less rich.

The relationship between the corrected CO EI and THC EI from the diamond probe compared well with the traverse average when plotted against the measured F/A ratio in figures 40, 42, 47, and 54. Similar relationships indicate that NO_x EI from the diamond probe is less than the traverse average at the 2- and 7-inch locations (figures 44 and 51). NO_x EI agreement at high power is good at the 7-inch axial location of the probe and improved at low power when the probe is positioned 10 inches downstream of the exhaust nozzle.

When the pollutants from the traverse average are plotted against those from the diamond probe, the situation is changed. With the diamond probe located in the 2-inch position and at idle mode, CO and THC EI were rich or higher than that of the traverse by 5 and 10 percent, respectively. NO_x EI at high power was somewhat less than the traverse average. When the diamond probe was

TABLE 5. T PROBE TEST RESULTS

Mode	Axial Location Inches	Radius Percent	N	CO EI $\overline{X}$	CO EI S	CO EI Percent Traverse Average	THC EI $\overline{X}$	THC EI S	THC EI Percent Traverse Average	NO_x EI $\overline{X}$	NO_x EI S	NO_x EI Percent Traverse Average
Idle	2	63	15	51.68	3.4	108.2	13.80	1.80	126.5	3.11	.90	87.1
Idle	2	66	2	50.27	–	105.3	11.33	–	103.8	3.09	–	86.6
Idle	2	70	2	47.59	–	99.7	10.40	–	95.3	3.36	–	94.1
Idle	2											
Idle	10	66	2	43.85	–	91.8	9.79	–	89.7	3.40	–	95.4
Idle	10	68	2	40.55	–	84.9	6.91	–	63.3	2.65	–	74.2
Idle	10	70	2	37.57	–	78.7	3.37	–	30.9	2.61	–	73.8
Approach	2	63	16	14.56	0.77	106.9	1.84	0.60	197.8	6.14	0.62	98.1
Approach	2	66	1	14.85	–	109.0	1.52	–	163.4	5.40	–	86.3
Approach	2	68	2	6.50	–	–	0.98	–	105.4	5.95	–	
Approach	2	70	2	13.04	–	95.70	1.77	–	190.3	5.42	–	86.6
Approach	10	66	2	13.20	–	96.9	0.98	–	105.4	5.16	–	82.4
Approach	10	68	2	8.19	–	–	1.05	–	112.9	5.68	–	90.7
Approach	10	70	2	11.43	–	83.9	0.52	–	56.4	5.26	–	84.0
Cruise	2	63	16	3.31	0.17	104.4	–	–	–	11.10	0.87	94.8
Cruise	2	66	2	3.30	–	104.4	–	–	–	10.37	–	88.1
Cruise	2	68	2	3.03	–	95.7	–	–	–	8.90	–	76.0
Cruise	2	70	2	3.70	–	116.7	–	–	–	11.16	–	95.3
Cruise	10	66	2	3.06	–	96.5	–	–	–	10.76	–	91.9
Cruise	10	68	2	2.48	–	78.2	–	–	–	10.66	–	91.0
Cruise	10	70		3.11	–	98.1	–	–	–	9.57	–	81.7
Max. Cont.	2	63	16	2.46	0.30	93.2	–	–	–	12.87	0.79	95.6
Max. Cont.	2	66	2	2.32	–	87.9	–	–	–	12.89	–	95.8
Max. Cont.	2	68	2	2.44	–	92.4	–	–	–	12.67	–	94.1
Max. Cont.	2	70	2	2.62	–	99.2	–	–	–	13.91	–	103.3
Max. Cont.	10	66		3.44	–	130.3	–	–	–	12.98	–	96.4
Max. Cont.	10	68		1.91	–	72.3	–	–	–	13.53	–	100.5
Max. Cont.	10	70		1.87	–	70.8	–	–	–	12.38	–	92.0
Takeoff	2	63	7	1.98	0.12	–	–	–	–	15.38	1.21	–
Takeoff	2	66	1	1.80	–	–	–	–	–	14.97	–	–
Takeoff	2	68	1	1.80	–	–	–	–	–	14.85	–	–
Takeoff	2	70	1	2.14	–	–	–	–	–	16.79	–	–
Takeoff	10	66	1	3.85	–	–	–	–	–	14.79	–	–
Takeoff	10	68	1	1.43	–	–	–	–	–	16.94	–	–
Takeoff	10	70	1	1.88	–	–	–	–	–	14.78	–	–

located 7 inches behind the exhaust nozzle, CO measurement agreed closely with the traverse average and THC samples were approximately 4-percent rich. The oxides of nitrogen measurements generally agreed with the traverse under high engine power conditions (table 6). When the diamond probe was positioned 10 inches downstream of the nozzle, and at low power, CO was somewhat less than the traverse average. However, the THC measurements were extremely low, being 33 percent less than the traverse average. This THC problem was considered to have been caused by a loss of heat and lowered temperature in the probe. Such a condition would result in loss of a portion of the sample consisting of the high molecular weight hydrocarbons in the probe. At approach power the THC measurement was higher than the traverse average, which indicates recovery of a portion of the sample.

The effect of probe axial location downstream of the exhaust nozzle is shown in figures 60, 61, and 62. CO EI decreases about 8 percent from the 2-inch to the 10-inch location. THC EI at idle power decreases about 5 percent from the 2-inch to the 7-inch position and decreases 39 percent at the 10-inch location. At maximum continuous and takeoff engine power, NO_x EI increases 6 and 9 percent as the probe is moved downstream to the 10-inch position.

EFFECT OF DIAMOND PROBE ON ENGINE PERFORMANCE.

The diamond probe was designed to be attached to and supported by the engine under test to prevent relative movement. Installation of the probe in proximity and attached to the exhaust nozzle may have adversely affected engine performance by aerodynamic drag forces and reduction in effective exhaust nozzle area. Engine performance with and without the diamond probe installed is shown in figures 63, 64, and 65. Each illustration depicts engine performance for one of the three probe axial locations of 2, 7, and 10 inches behind the exhaust nozzle.

When the diamond probe was located 2 inches behind the exhaust nozzle, significant changes occurred in engine pressure ratio (EPR), thrust, and low and high rotor speeds (N_1, N_2). The thrust was reduced approximately 4 percent at MCP, EPR increased 2.5 percent, and the rotor speeds decreased. When the probe was positioned 7 inches behind the exhaust nozzle, changes in EPR, N_1, and N_2 were minimal. Thrust was reduced from over 4 percent at cruise power and 5.8 percent at takeoff power. With the probe positioned 10 inches behind the nozzle, engine performance remained unchanged, with the exception of thrust reduction of up to 5.8 percent. In all cases, thrust reduction was attributed to the drag forces of the sample probe resulting from attaching and supporting the probe to the engine.

TABLE 6. DIAMOND PROBE TEST RESULTS

			CO EI			THC EI			NO_x EI		
Mode	Axial Location Inches	N	$\overline{X}$	S	Percent Traverse Average	$\overline{X}$	S	Percent Traverse Average	$\overline{X}$	S	Percent Traverse Average
Idle	2	6	50.22	3.01	105.2	12.01	2.7	110.1	2.54	0.42	71.1
Approach	2	6	14.57	1.33	106.9	1.74	0.53	187.1	6.10	0.77	97.4
Cruise	2	6	3.72	0.65	117.3	-	-	-	11.24	0.40	96.0
MCP	2	6	2.53	0.10	95.71	-	-	-	13.31	0.53	98.8
Takeoff	2	3	2.21	-	-	-	-	-	15.15	-	-
Idle	7	6	47.97	1.99	100.3	11.38	1.28	104.3	2.54	0.24	71.1
Approach	7	6	13.3	0.64	97.6	1.0	0.17	107.5	5.60	0.37	89.4
Cruise	7	5	3.26	0.55	106.0	-	-	-	10.99	0.56	92.3
MCP	7	6	2.30	0.26	87.1	-	-	-	13.97	0.57	103.8
Takeoff	7	3	1.98	-	-	-	-	-	15.67		-
Idle	10	2	45.95	-	96.2	7.30	-	66.9	2.74	-	76.8
Approach	10	2	13.42	-	98.5	1.13	-	121.5	6.1	-	97.4
Cruise	10	2	3.70	-	116.7	-	-	-	11.10	-	94.8
MCP	10	2	2.49	-	94.3	-	-	-	13.97	-	103.8
Takeoff	10	1	2.0	-	-	-	-	-	16.5	-	-

SUMMARY OF RESULTS

Emissions were measured on a 2-inch grid in the exhaust plume of mixed-flow TF30 turbofan engine at four engine power settings from idle through maximum continuous. The objectives were to establish a data base as required for calculating average emissions and to generate the maps and profiles required to design and evaluate fixed probes for acquiring representative samples. The emission profiles or gradients were unusually steep with maximum changes in emission levels of 40 to 50 percent per inch. Measurement efficiency of the traverses was near ideal under idle and approach power conditions; however, under high power conditions the traverses were somewhat lean.

An additional bearing support strut was installed in the core exhaust and was evaluated by conducting emission traverses at low and high engine power settings. The additional strut moved the local emissions outward toward the tailpipe or nozzle lip.

Calculated diamond probe performance was excellent for emission concentrations and emission indices while calculated cruciform probe performance based on area weighted traverse points was considered good for emission indices and poor for emission concentrations.

Four probes installed to sample undiluted core exhaust were utilized as a reference for all testing. The correlation between the traverse and the core probes, however, was not up to expectations with CO EI and THC EI higher than the traverse at low power.

A recommended probe in the shape of a diamond designed to sample on the 45° radii at 62 percent of the radius was evaluated at axial locations behind the exhaust nozzle of 2, 7, and 10 inches. When the probe was positioned 2 inches behind the nozzle, CO EI and THC EI were higher than the traverse average under low engine power. The oxides of nitrogen were closer to the traverse at high power. At the 7-inch axial probe location, CO EI agreed with that of the traverse and THC EI was slightly higher. The oxides of nitrogen were variably increasing with engine power. When the diamond probe was positioned 10 inches behind the exhaust nozzle, CO EI was somewhat less than the traverse average. THC EI, however, was extremely low (33 percent less than the traverse average). This problem was considered to have resulted from loss of heat and lowered temperature in the probe. Relocating the diamond probe from the 2-inch to the 10-inch axial position reduced the levels for CO and THC. Under high power (maximum continuous and takeoff), the levels of NO_x EI increased at approximately the same rate that CO EI deceased under low power conditions.

The effect of the axial position of the diamond probe behind the exhaust nozzle on engine performance was investigated. Location of the probe 2 inches behind the exhaust nozzle had significant effects on engine performance. Thrust loss was over 4 percent, engine pressure ratio increased 2.5 percent, and changes occurred in high and low rotor speeds. When the probe was positioned 7 inches behind the exhaust nozzle, engine performance changes were minimal with the exception of over 4 percent thrust reduction. Engine performance with

the exception of thrust was unchanged when the probe was placed 10 inches behind the exhaust nozzle. Engine thrust reduction was attributed to supporting the probe from the engine. The thrust loss resulted from aerodynamic drag of the probe in the high velocity exhaust gases.

CONCLUSIONS

1. The exhaust plume of mixed flow TF30 turbofan engine is characterized by steep emission gradients.

2. The immersion depth for average emissions on both the 45° and 90° radii remains essentially constant as engine power is varied.

3. Based on calculations of area weighting the traverse points, cruciform sample probes will provide representative emission indices but nonrepresentative volumetric concentrations.

4. A fixed 12-point probe in the shape of a diamond was determined by the results of interpolation and calculations based on the traverse maps and probe tests results to provide representative emission samples.

REFERENCES

1. Clean Air Amendments of 1970, Public Law 91-604, 91st Congress, H.R. 17255, December 31, 1970.

2. McAdams, H. T., Analysis of Aircraft Exhaust Emission Measurements Statistics, EPA Technical Report NA 5007-K-2.

3. Allen, L., Slusher, G. R., Ambient Temperature and Humidity Correction Factors for Exhaust Emissions from Two Classes of Aircraft Turbine Engines, FAA Technical Report FAA-RD-76-149.

4. Slusher, G. R., Analytical Study of Mixed-Flow JT8D Exhaust Emissions Measurements for Fixed Probe Requirements, Technical Report FAA-RD-76-140.

5. Slusher, G. R., Emission Sample Probe Investigation of a Mixed Flow JT8D-11 Turbofan Engine, Technical Report FAA-RD-77-175.

6. Klueg, E. P. and Slusher, G. R., Exhaust Emission Probe Investigation of a Mixed-Flow Turbofan Engine, Technical paper presented before the October 1974 meeting of the Instrument Society of America, New York, New York, 1974.

7. Souza, A. F., Further Investigation into the Causes of Variability in Aircraft Turbine Engine Emission Measurement, Technical Report EPA-460/3-75-011.

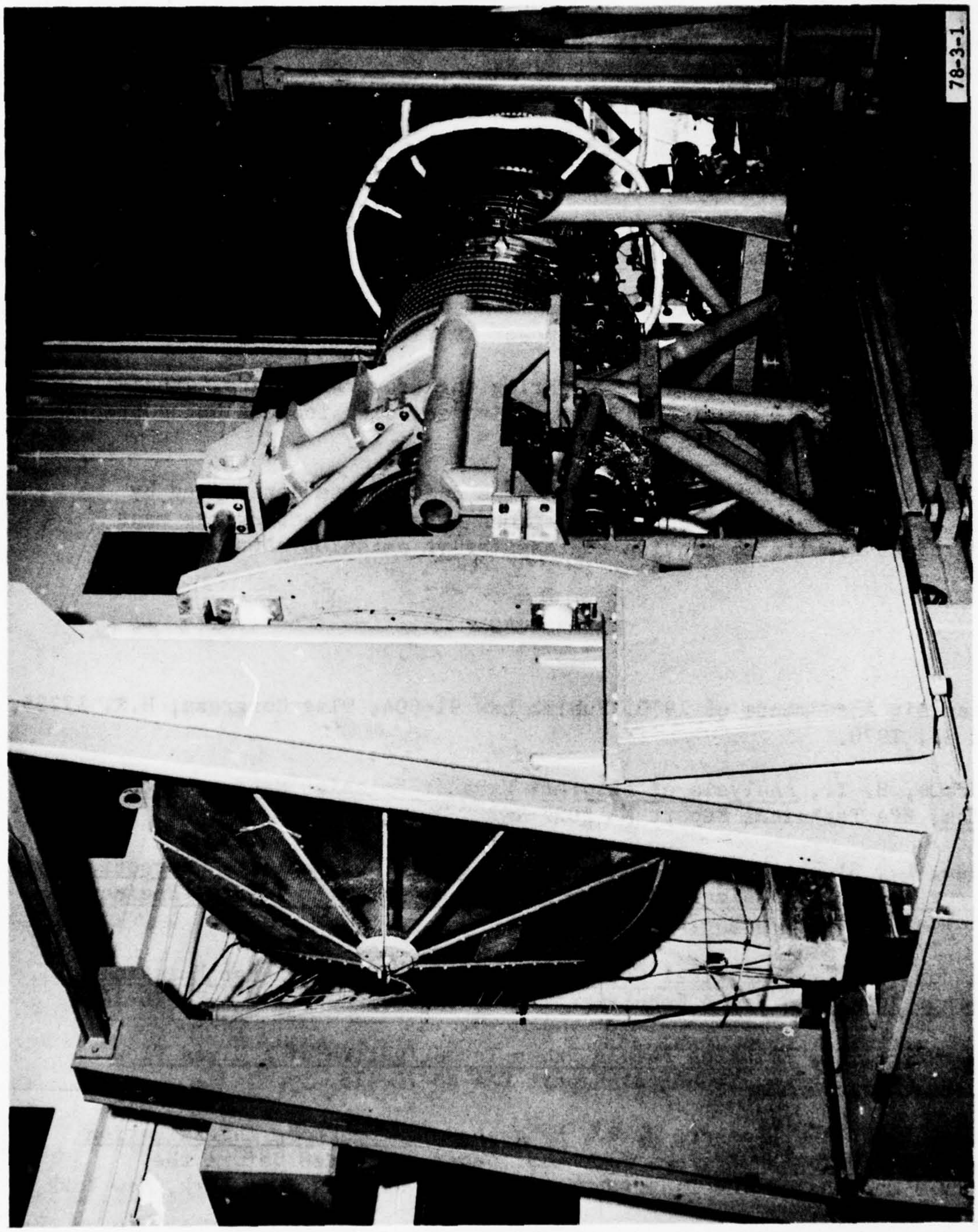


FIGURE 1. TF30 ENGINE TEST INSTALLATION

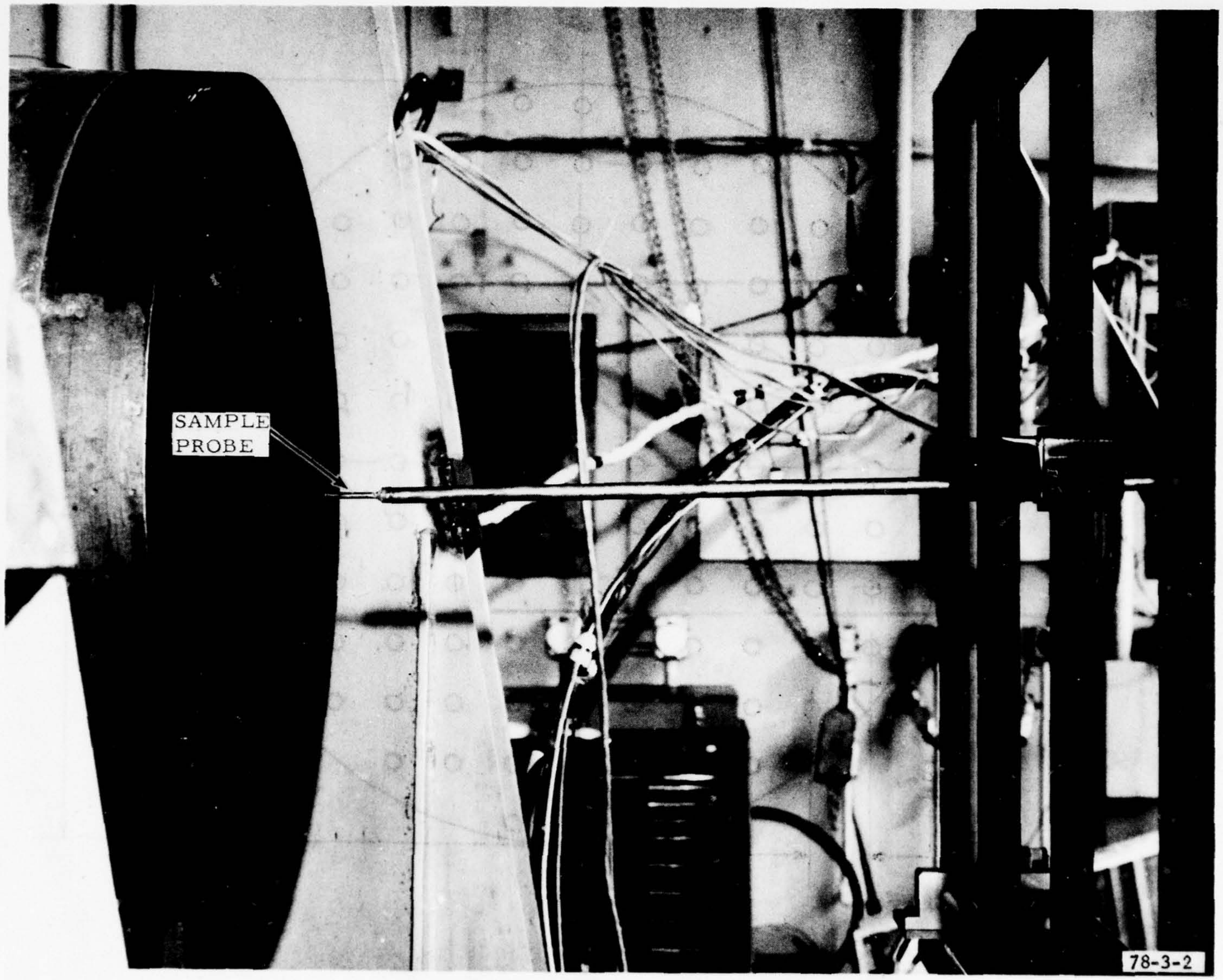


FIGURE 2. TRAVERSE PROBE MECHANISM

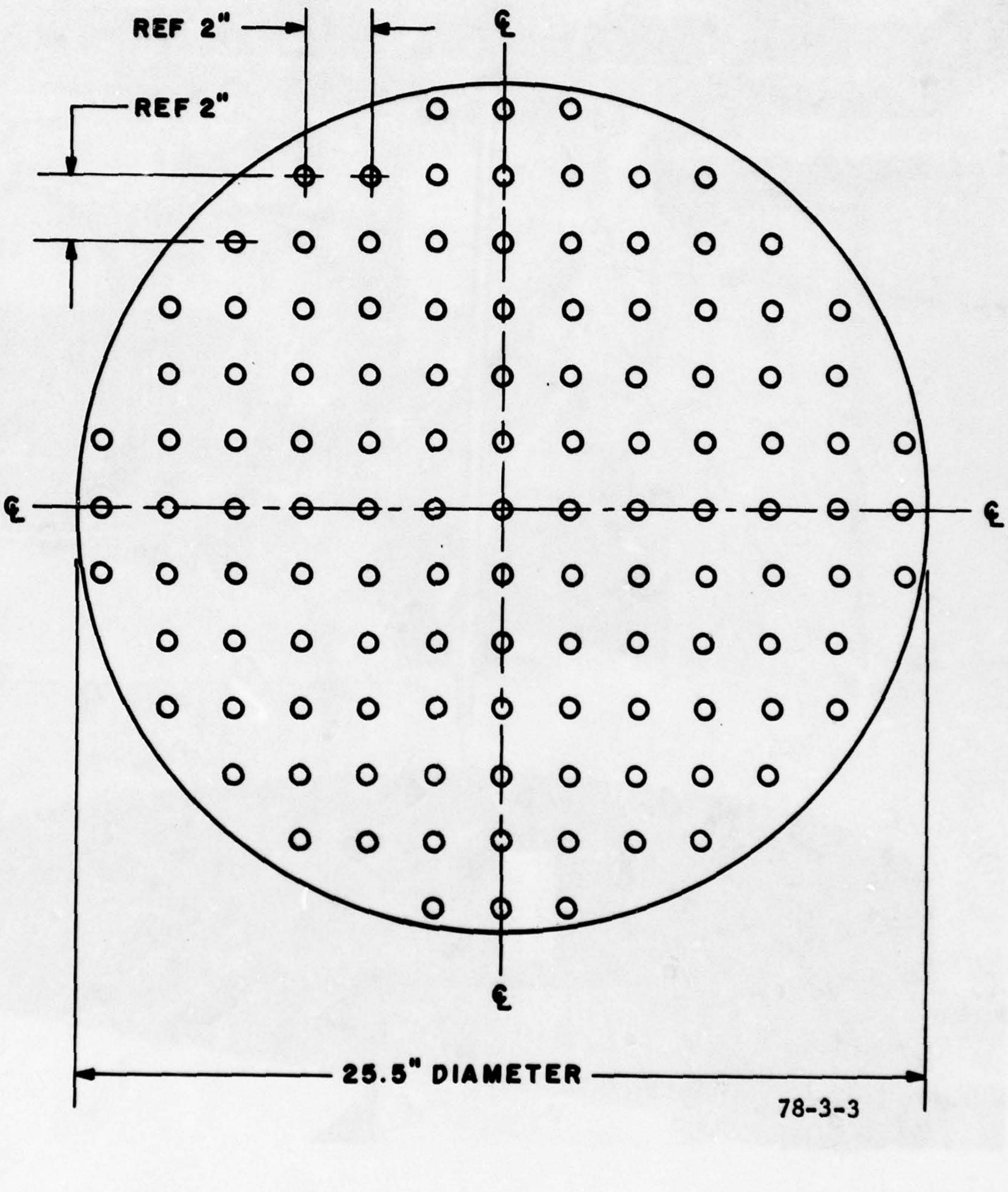


FIGURE 3. TRAVERSE EMISSION SAMPLE POINTS (121)

FIGURE 4. CORE EMISSION SAMPLE PROBES

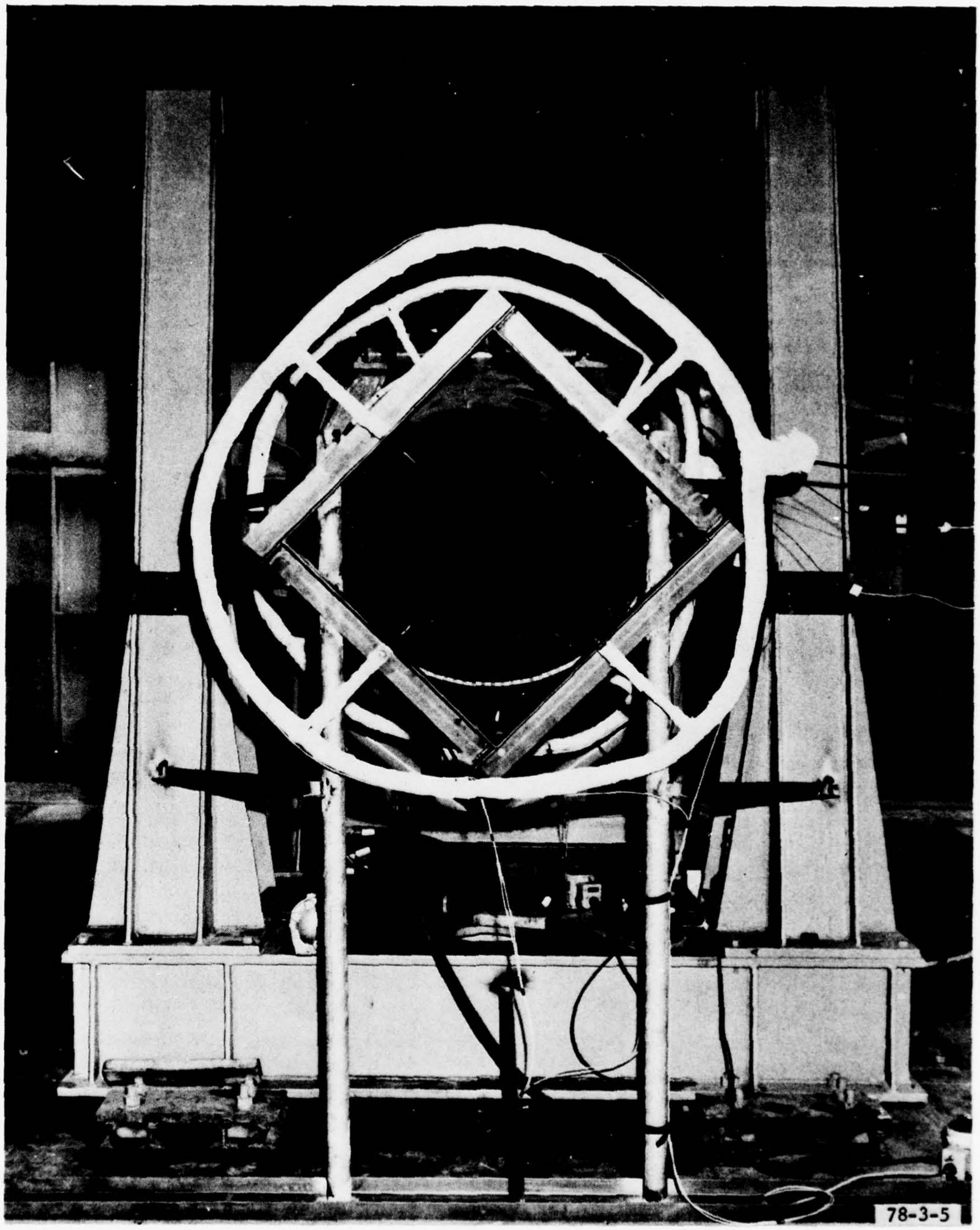


FIGURE 5.   T PROBES

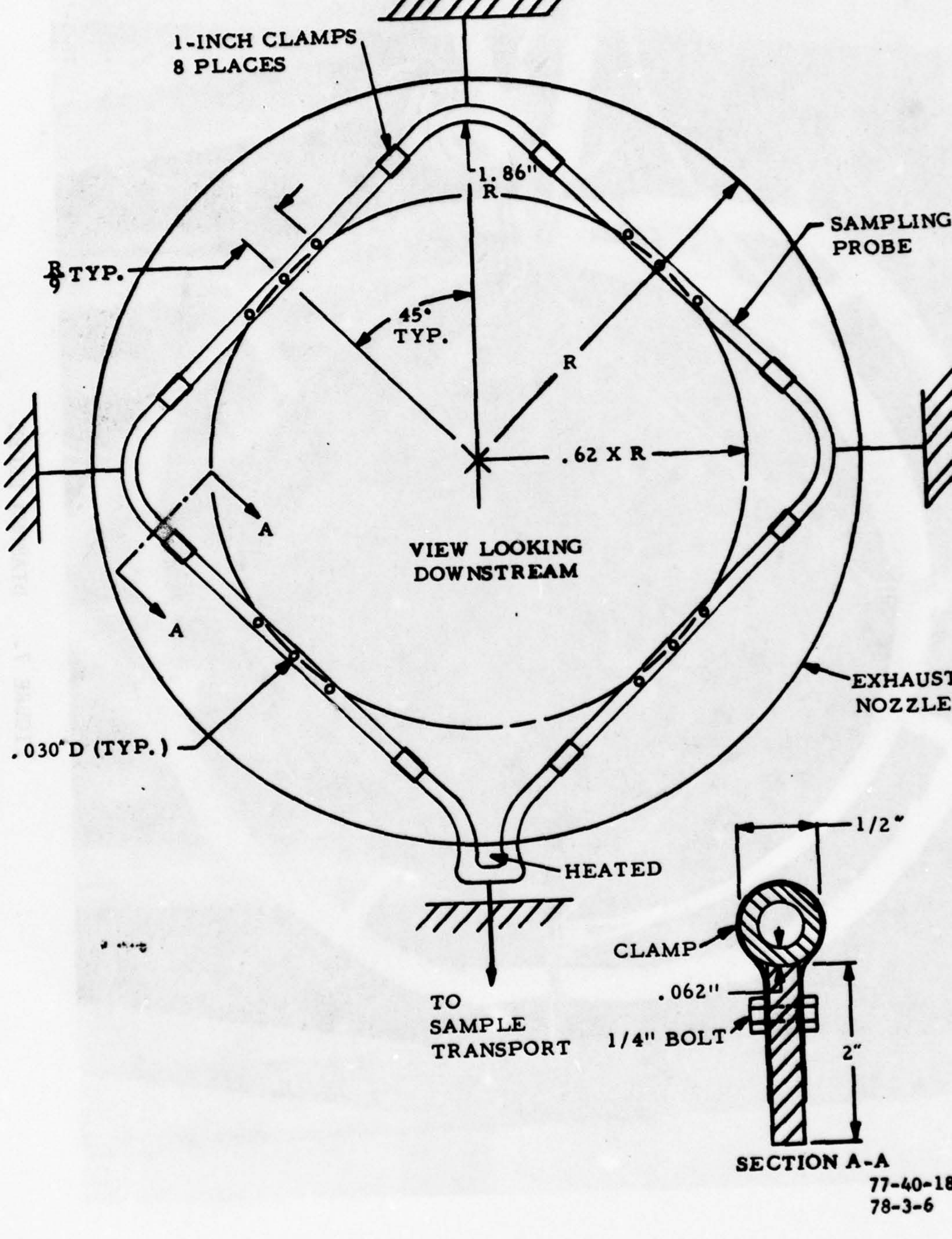


FIGURE 6. RECOMMENDED EMISSION SAMPLING PROBE

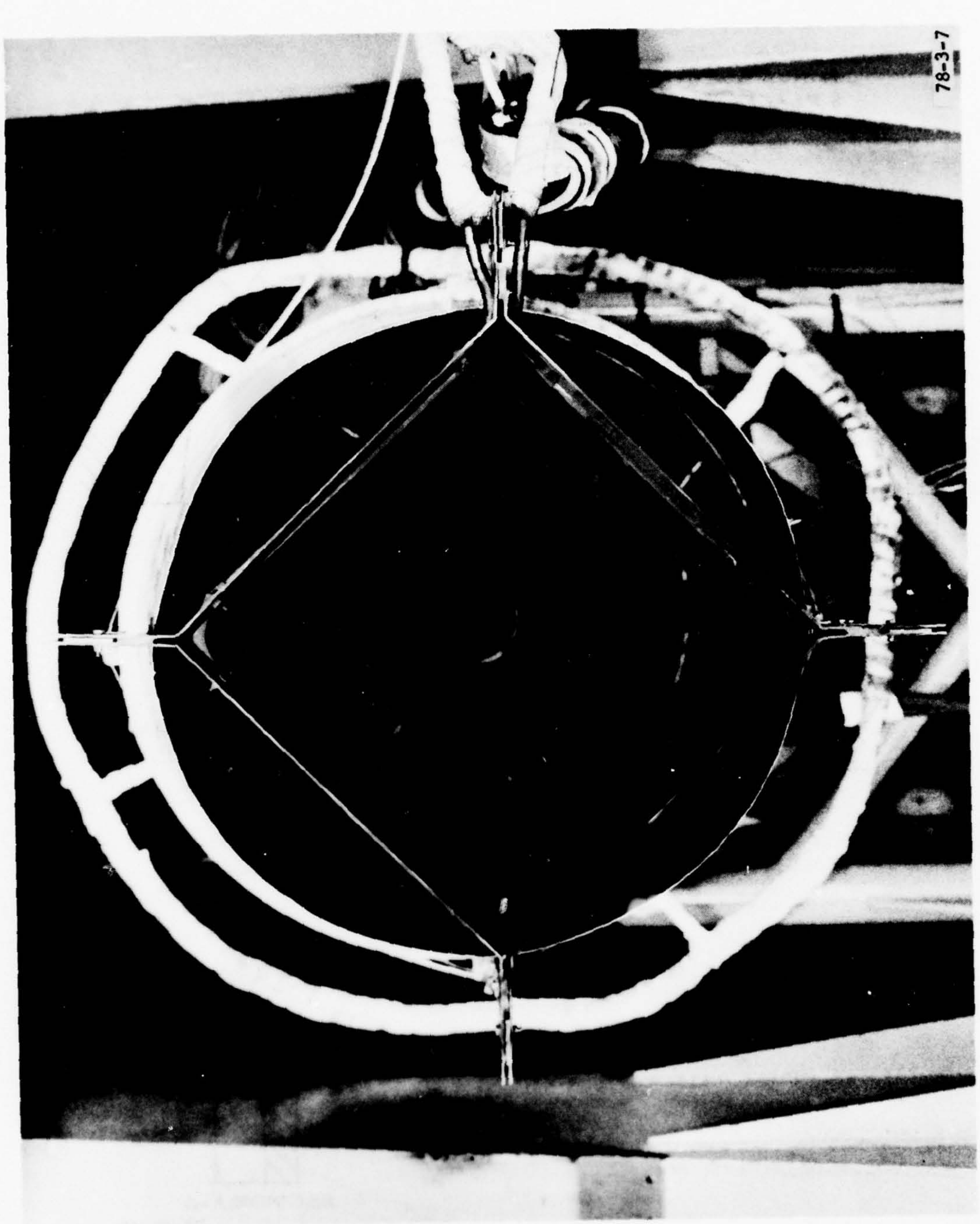
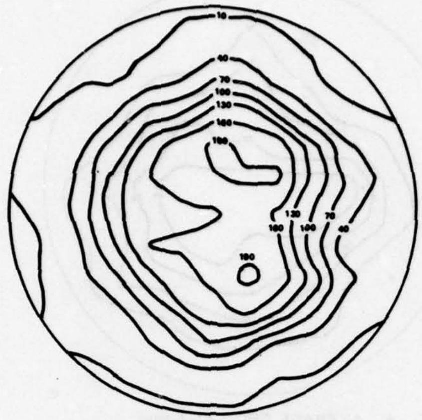
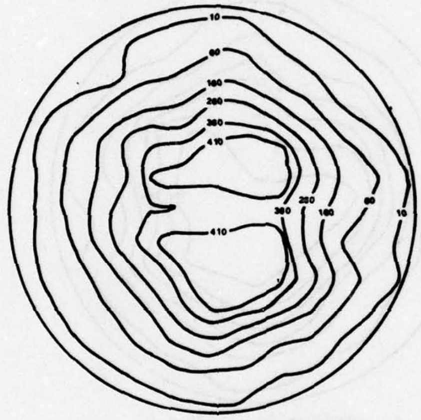


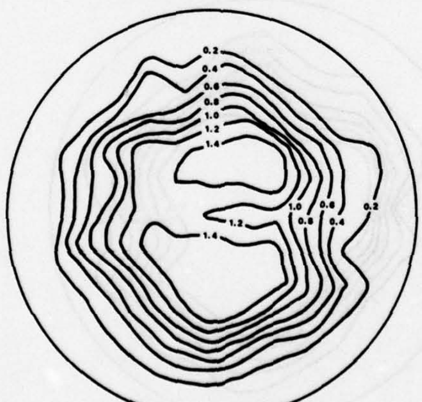
FIGURE 7. DIAMOND PROBE



A. AVERAGE THC = 71.03 ppm
CORRECTED THC = 10.91 EI



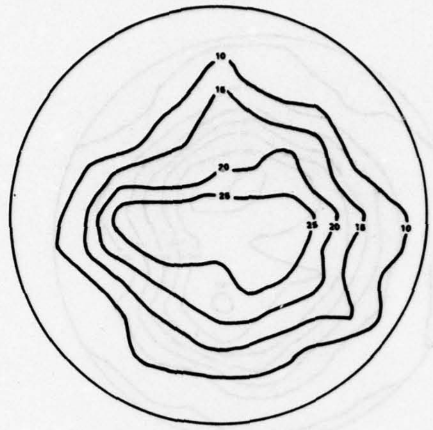
B. AVERAGE CO = 163 ppm
CORRECTED CO = 48.39 EI



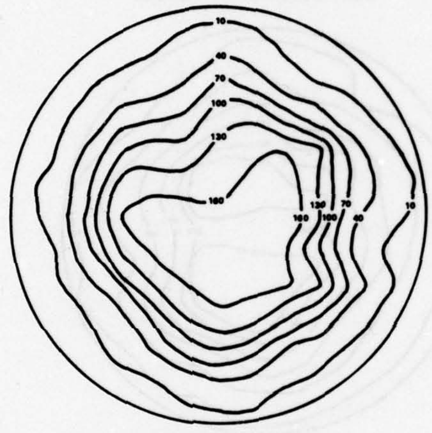
78-3-8

C. AVERAGE CO_2 = 0.58%

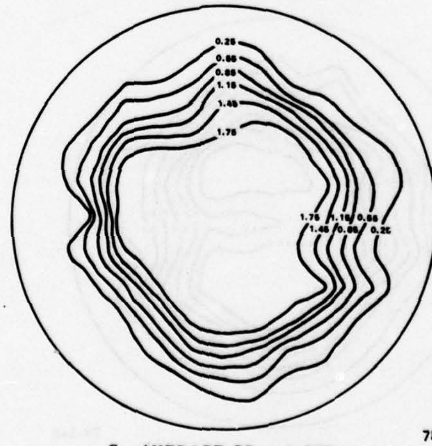
FIGURE 8. EXHAUST EMISSION TRAVERSE MAPS--IDLE POWER



A. AVERAGE THC = 13.2 ppm
CORRECTED THC = 0.93 EI



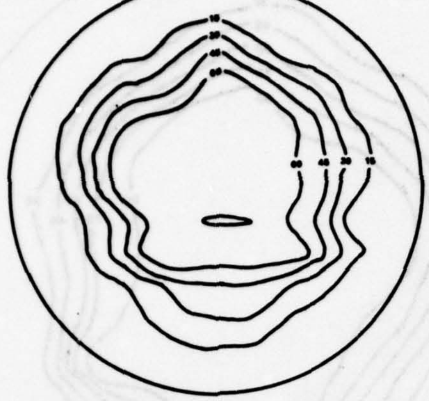
B. AVERAGE CO = 66.75 ppm
CORRECTED CO = 13.62 EI



78-3-9

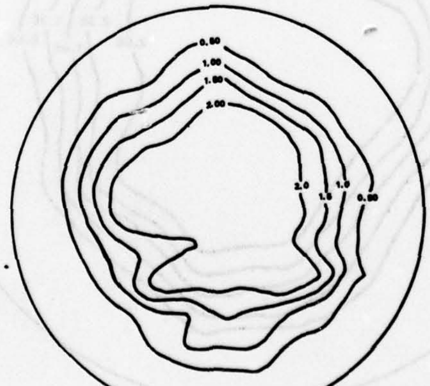
C. AVERAGE CO_2 = 0.85%

FIGURE 9. EXHAUST EMISSION TRAVERSE MAPS--APPROACH POWER



A. AVERAGE NO_X 28.64 ppm
CORRECTED NO_X = 11.71 EI

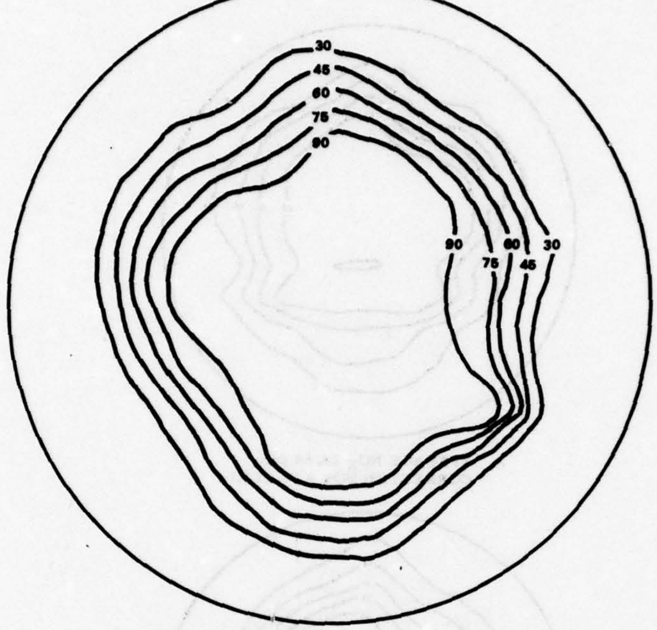
B. AVERAGE CO = 16.25 ppm
CORRECTED CO = 3.17 EI



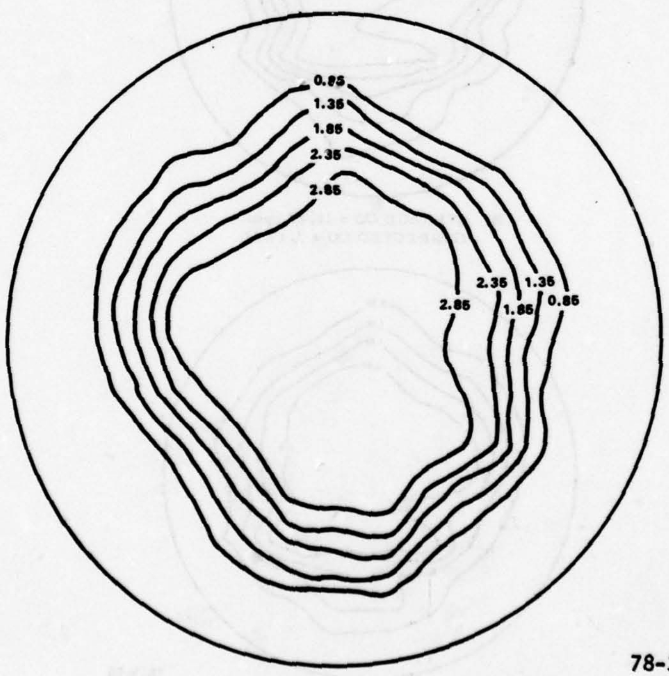
78-3-10

C. AVERAGE CO_2 = 0.957%

FIGURE 10. EXHAUST EMISSION TRAVERSE MAPS--CRUISE POWER



A. AVERAGE NO_X = 45.3 ppm
CORRECTED NO_X = 12.93 EI

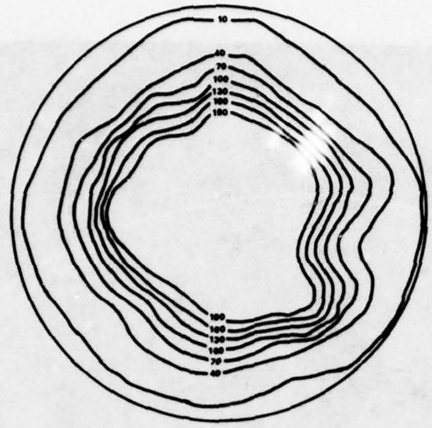


78-3-11

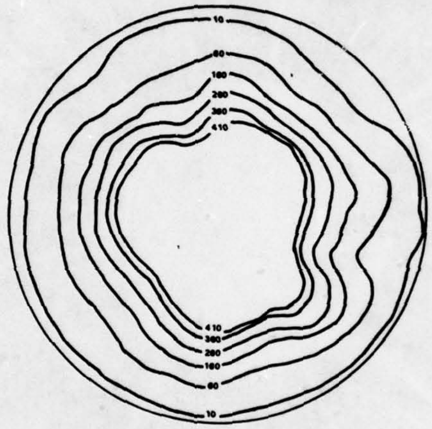
B. AVERAGE CO_2 = 1.35%

FIGURE 11. EXHAUST EMISSION TRAVERSE MAPS--MAXIMUM CONTINUOUS POWER

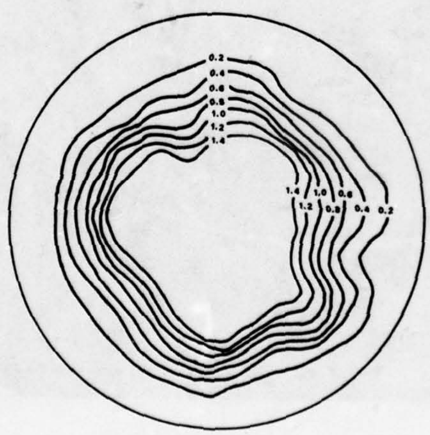
FIGURE 12. TURBINE BEARING SUPPORT MODIFICATION



A. AVERAGE THC = 103 ppm
CORRECTED THC = 10.90 EI



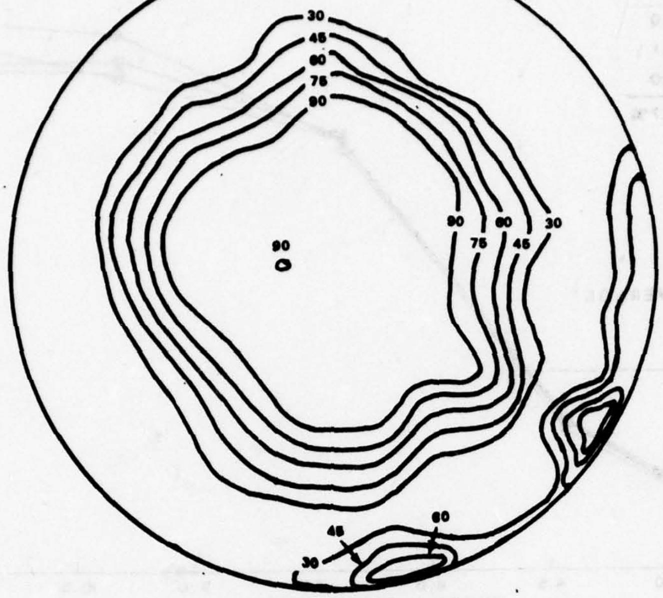
B. AVERAGE CO = 206 ppm
CORRECTED CO = 47.12 EI



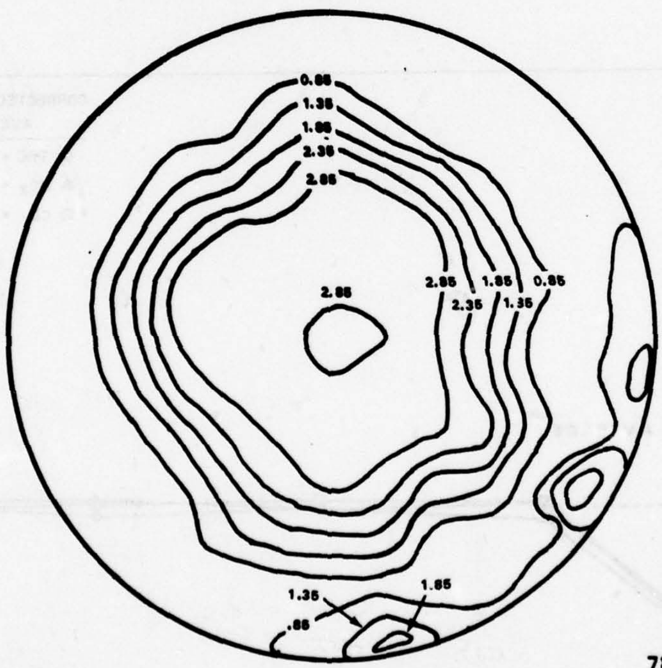
78-3-13

C. AVERAGE CO_2 = 0.69

FIGURE 13. EXHAUST EMISSION TRAVERSE MAPS--EXTRA STRUT--IDLE POWER



A. AVERAGE NO_X = 48 ppm
CORRECTED NO_X = 13.99 EI



78-3-14

B. AVERAGE CO_2 = 1.43%

FIGURE 14. EXHAUST EMISSION TRAVERSE MAPS--EXTRA STRUT--MAXIMUM CONTINUOUS POWER

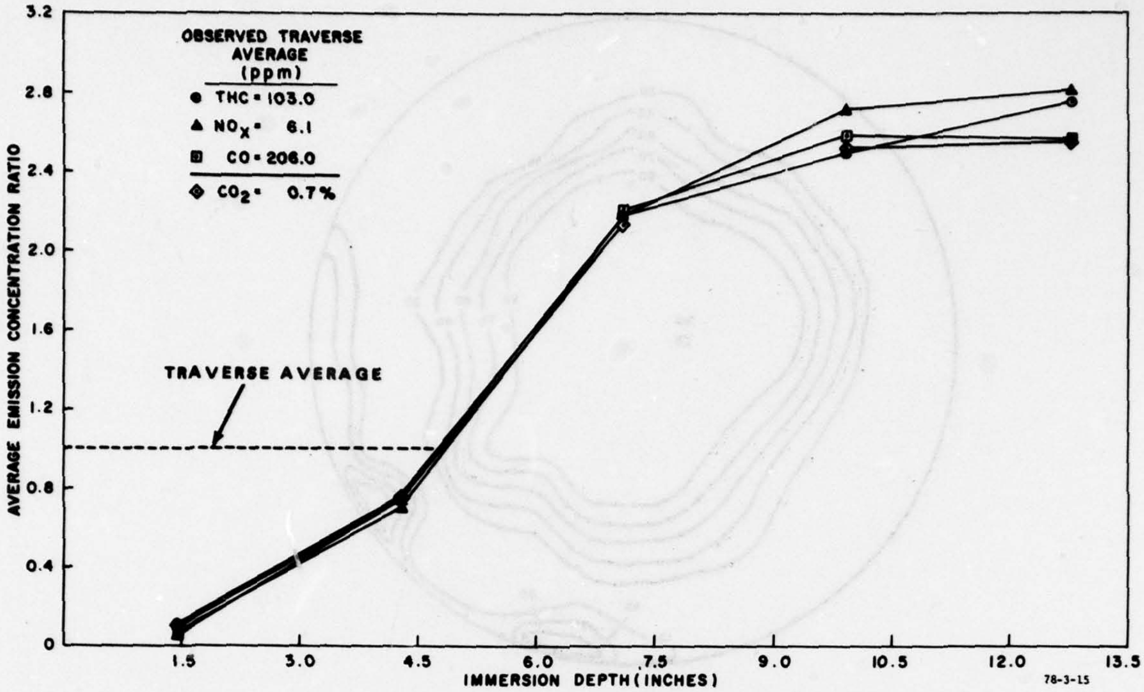


FIGURE 15(a). EMISSION CONCENTRATION DISTRIBUTION--45°--IDLE POWER

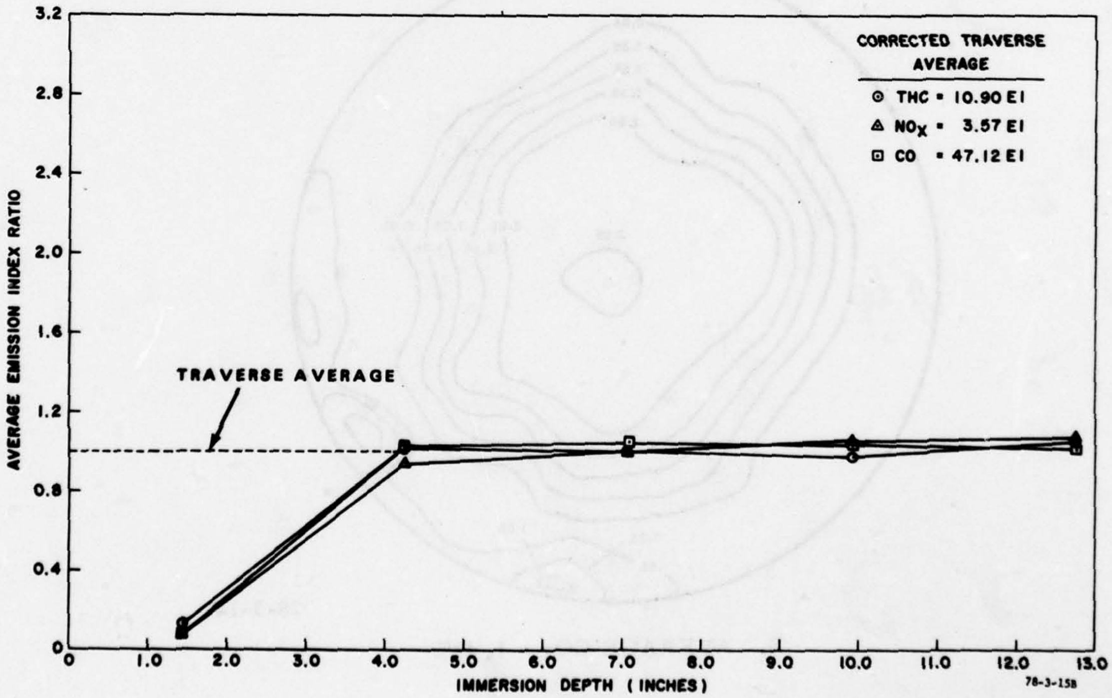


FIGURE 15(b). EMISSION INDEX DISTRIBUTION--45°--IDLE POWER

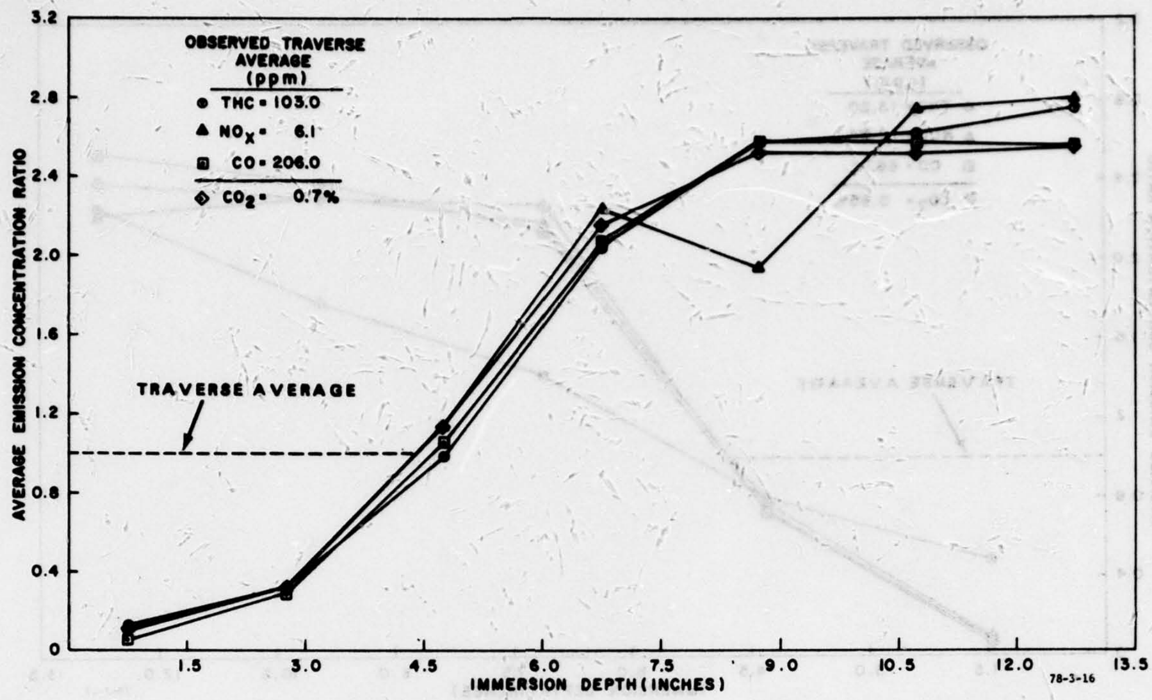


FIGURE 16(a). EMISSION CONCENTRATION DISTRIBUTION--90°--IDLE POWER

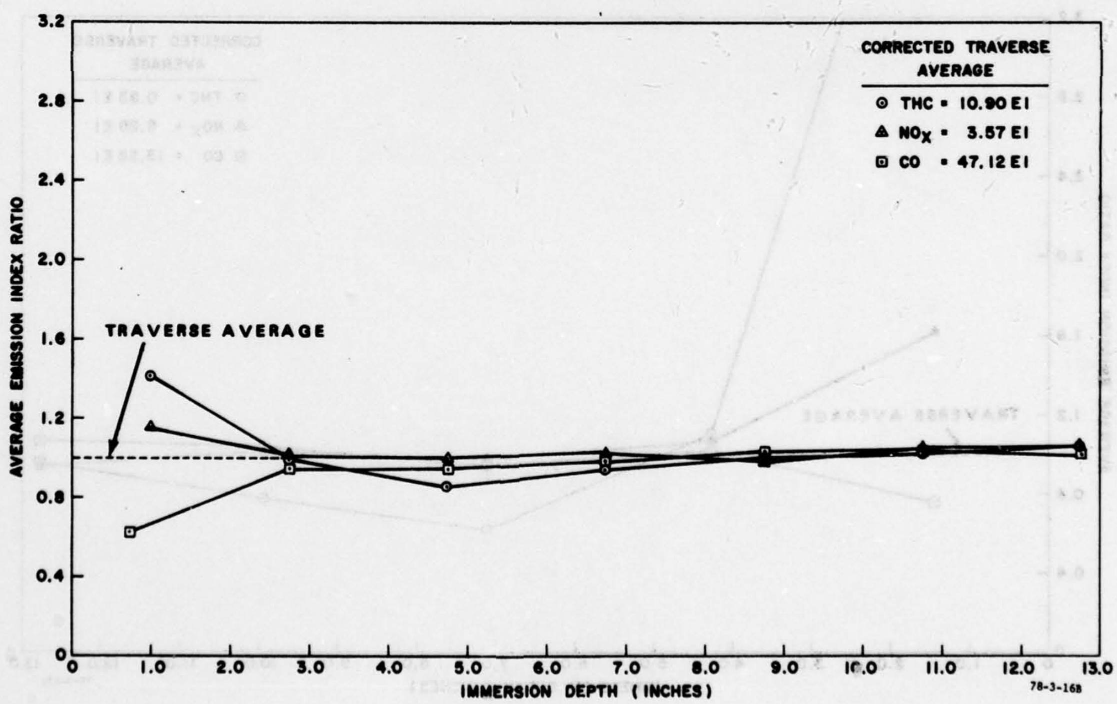


FIGURE 16(b). EMISSION INDEX DISTRIBUTION--90°--IDLE POWER

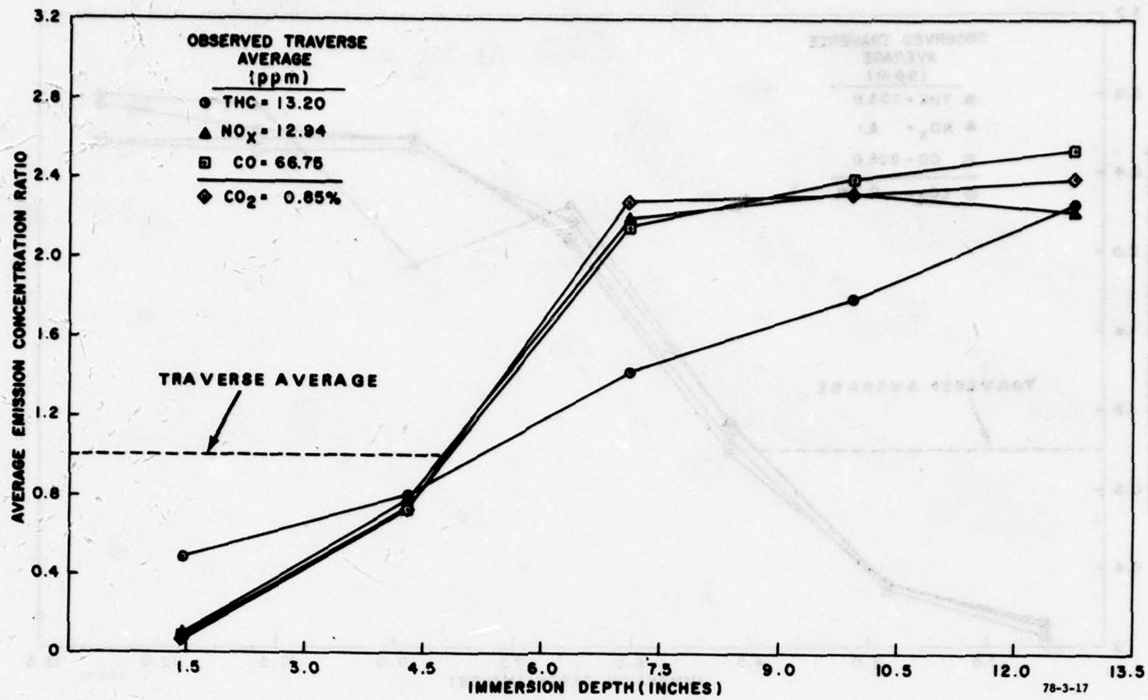


FIGURE 17(a). EMISSION CONCENTRATION DISTRIBUTION--45°--APPROACH POWER

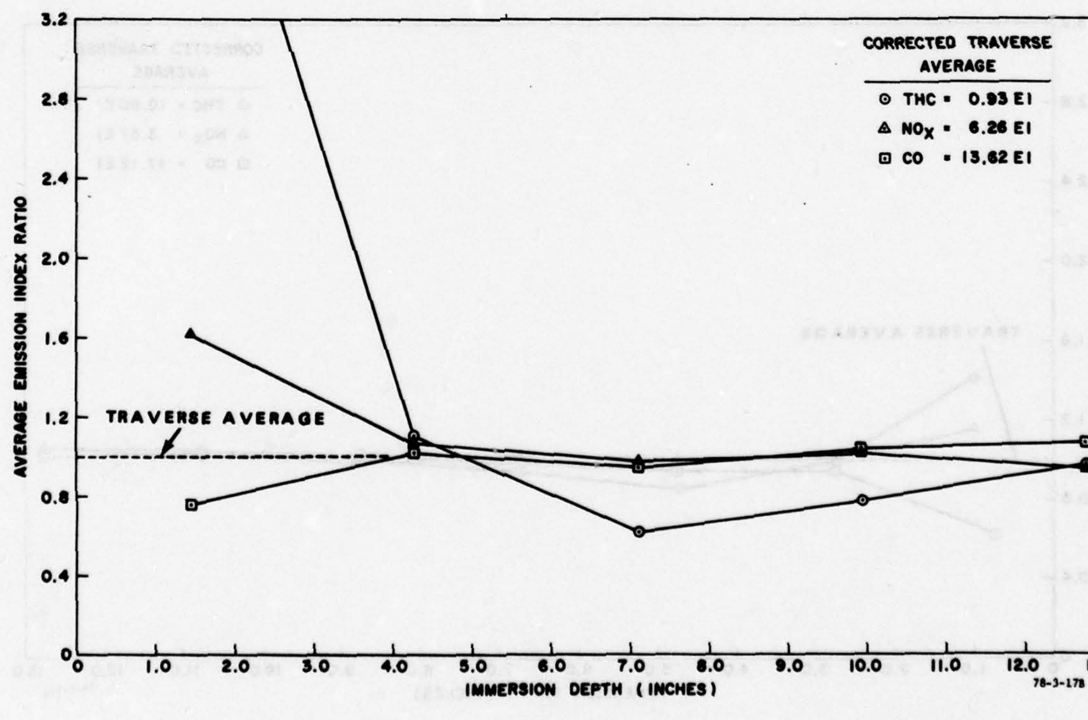


FIGURE 17(b). EMISSION INDEX DISTRIBUTION--45°--APPROACH POWER

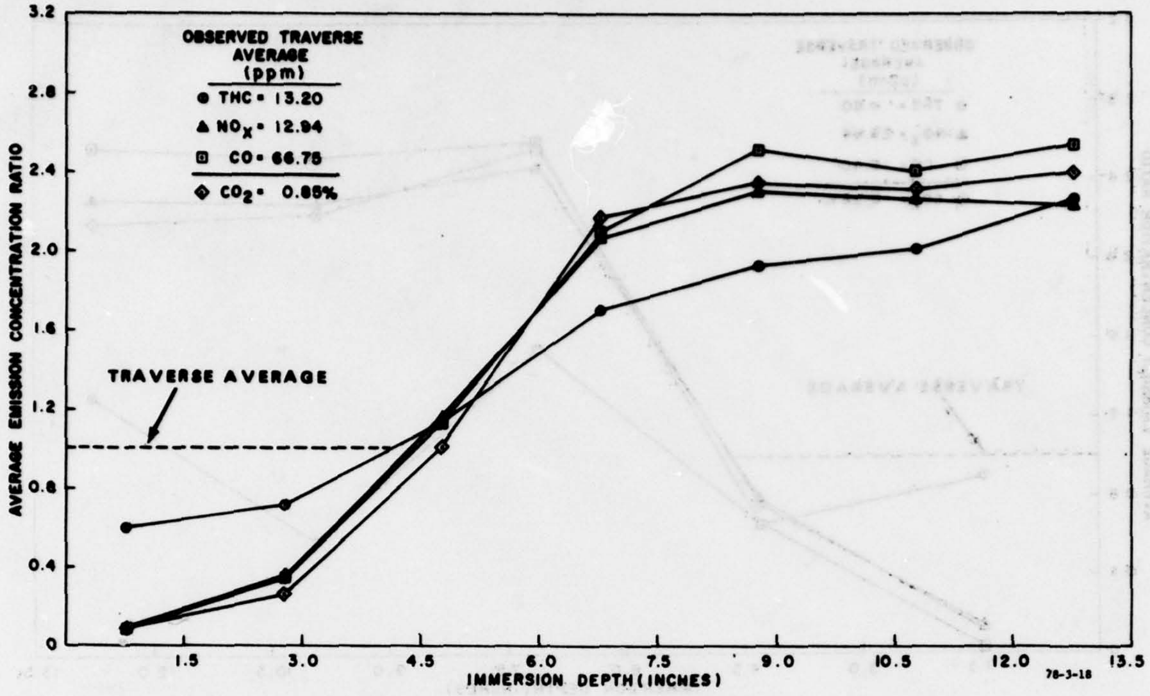


FIGURE 18(a). EMISSION CONCENTRATION DISTRIBUTION--90°--APPROACH POWER

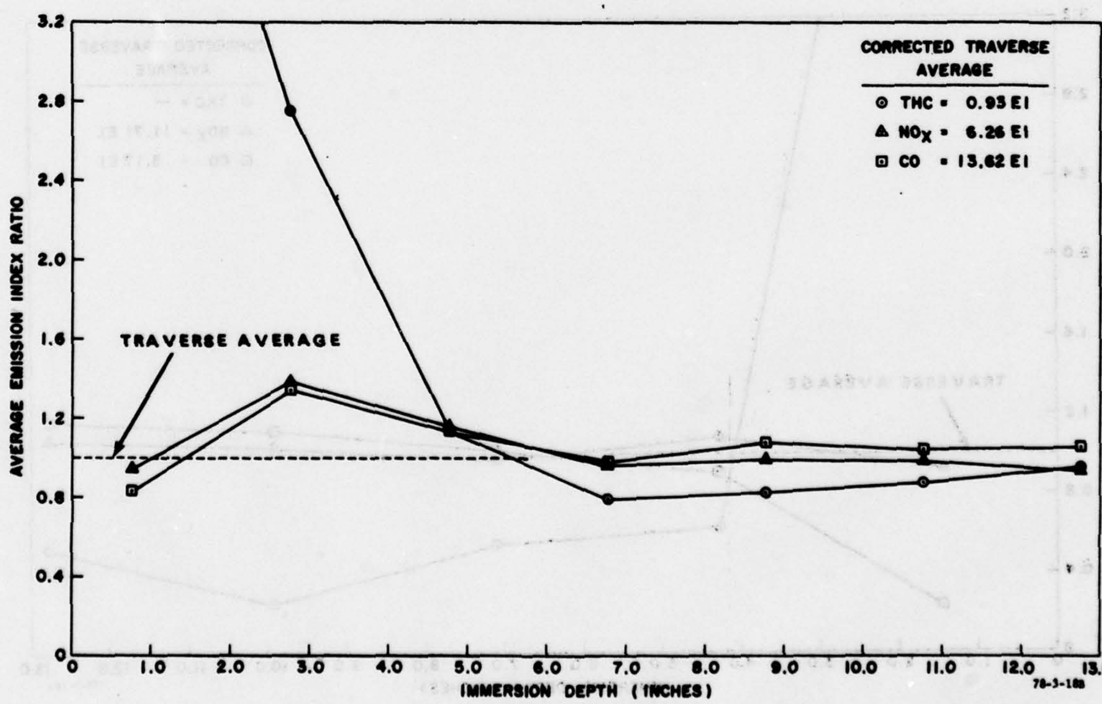


FIGURE 18(b). EMISSION INDEX DISTRIBUTION--90°--APPROACH POWER

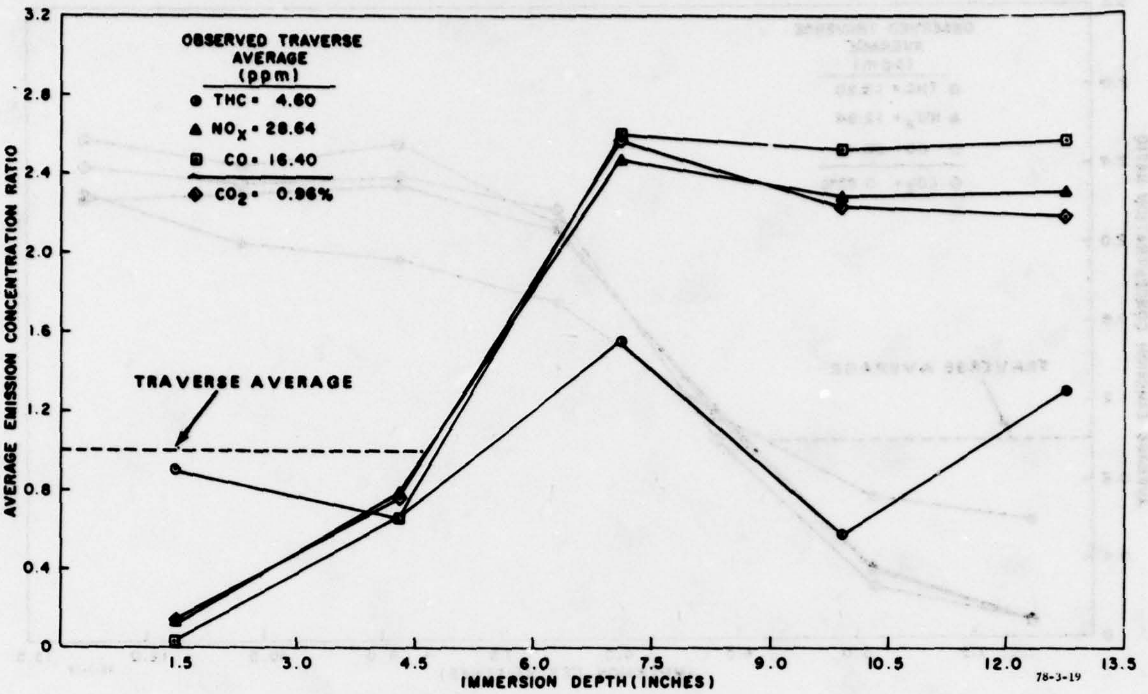


FIGURE 19(a). EMISSION CONCENTRATION DISTRIBUTION--45°--CRUISE POWER

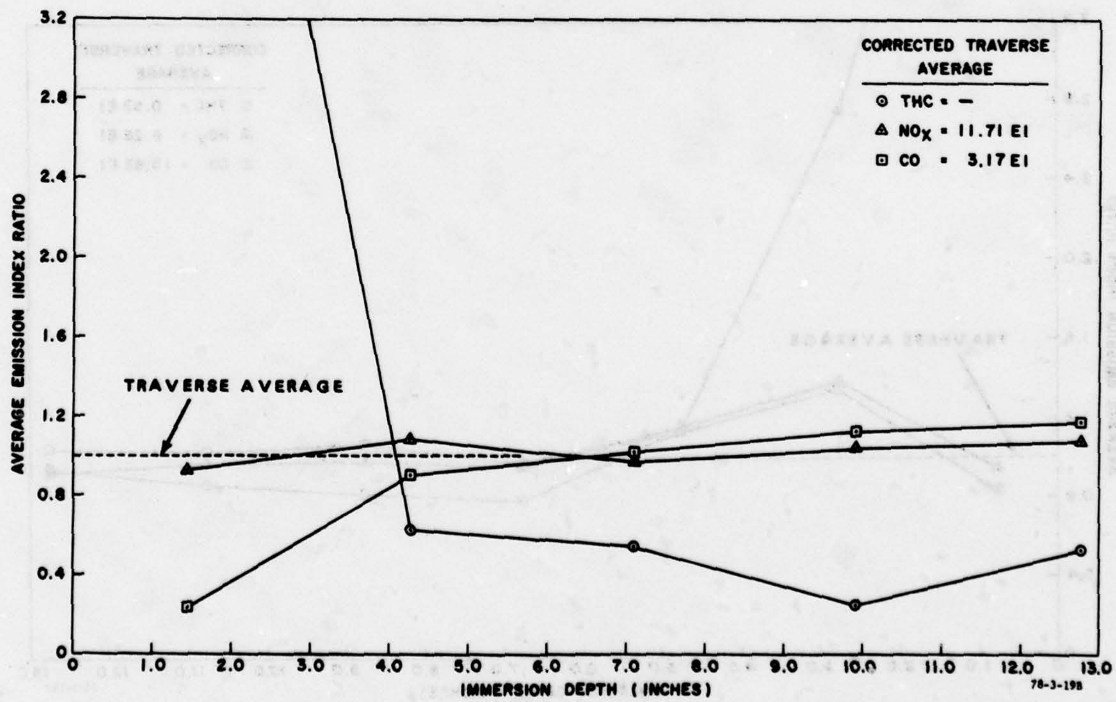


FIGURE 19(b). EMISSION INDEX DISTRIBUTION--45°--CRUISE POWER

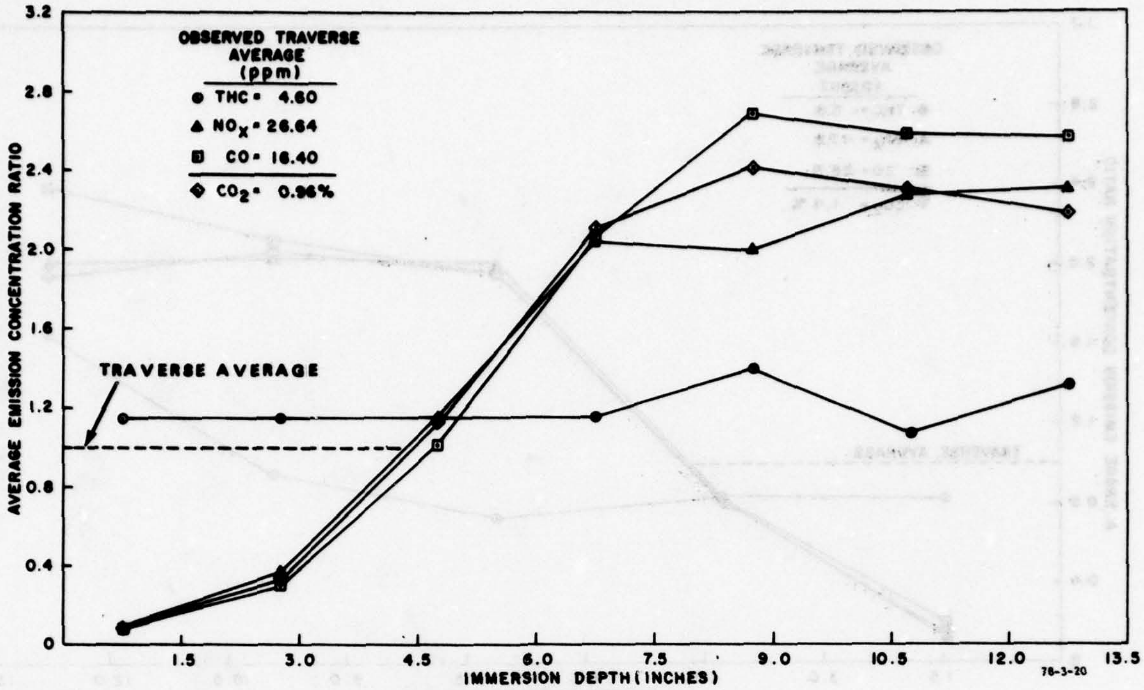


FIGURE 20(a). EMISSION CONCENTRATION DISTRIBUTION--90^{O}--CRUISE POWER

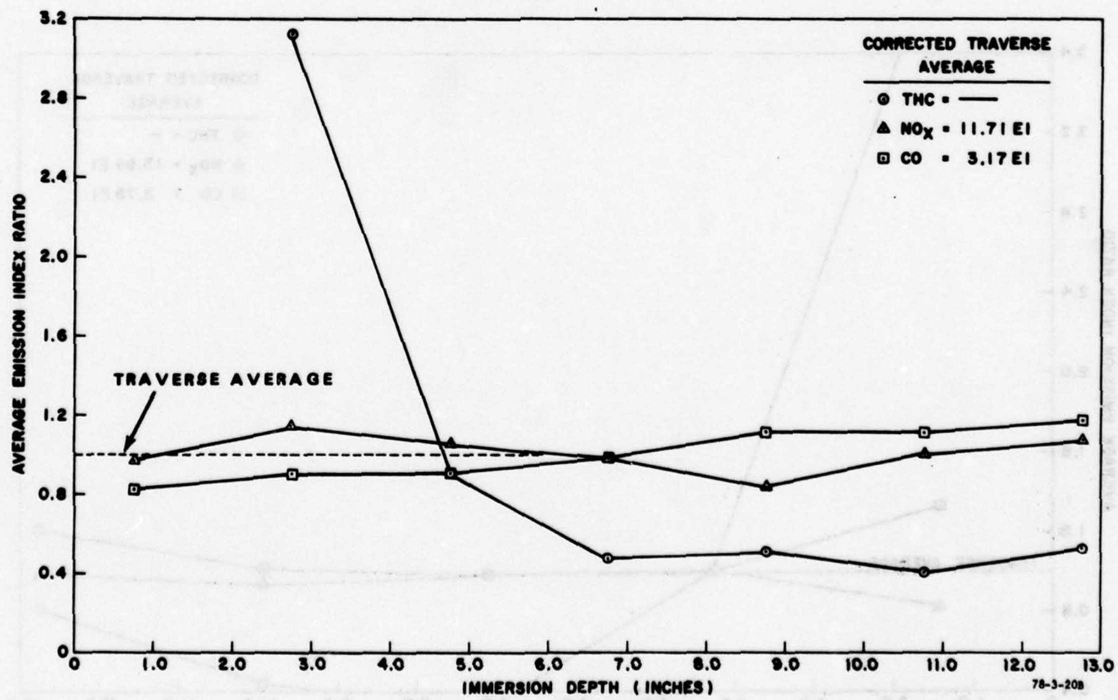


FIGURE 20(b). EMISSION INDEX DISTRIBUTION--90^{O}--CRUISE POWER

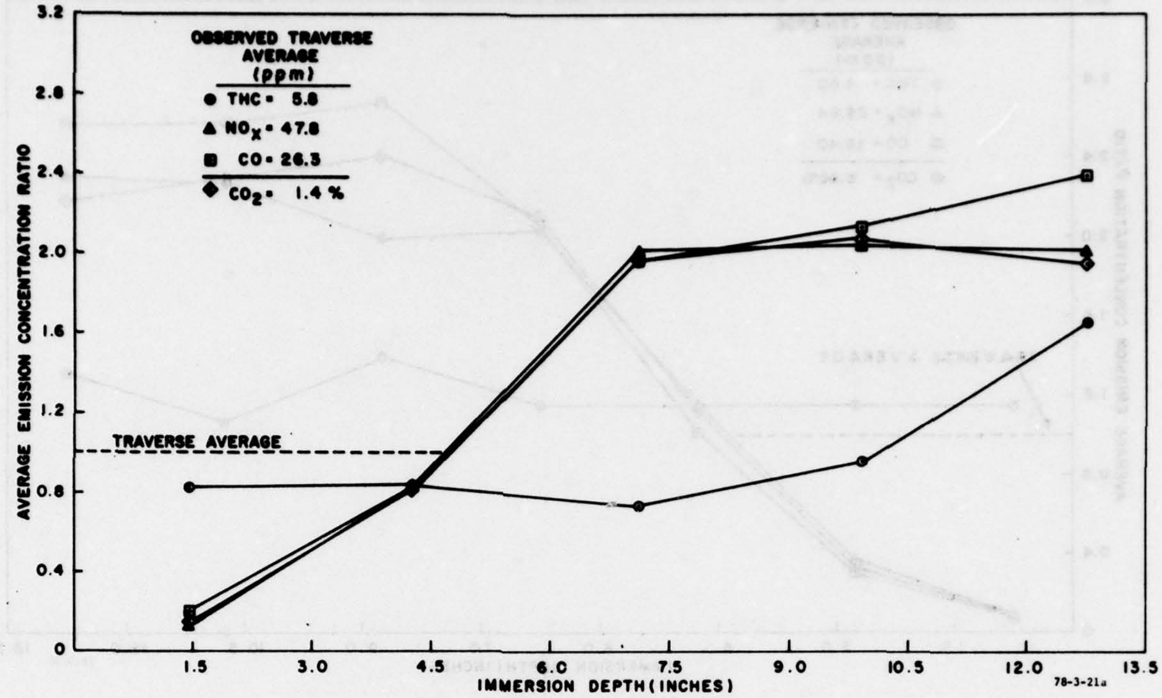


FIGURE 21(a). EMISSION CONCENTRATION DISTRIBUTION--45°-- MAXIMUM CONTINUOUS POWER

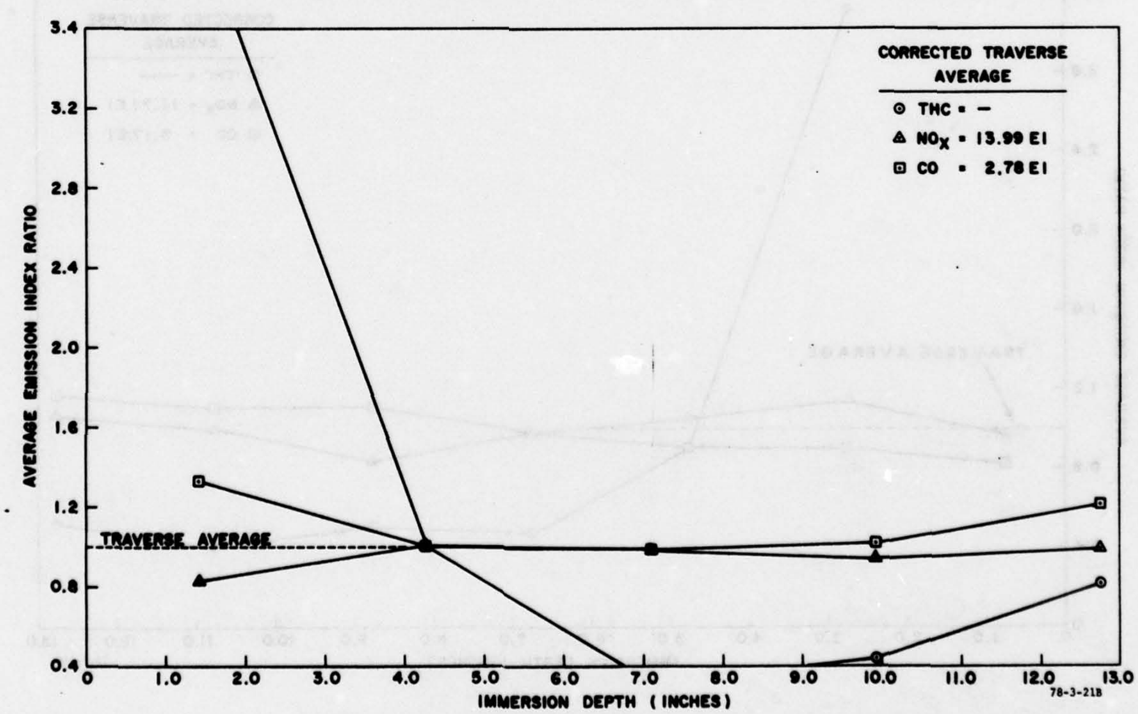


FIGURE 21(b). EMISSION INDEX DISTRIBUTION--45°-- MAXIMUM CONTINUOUS POWER

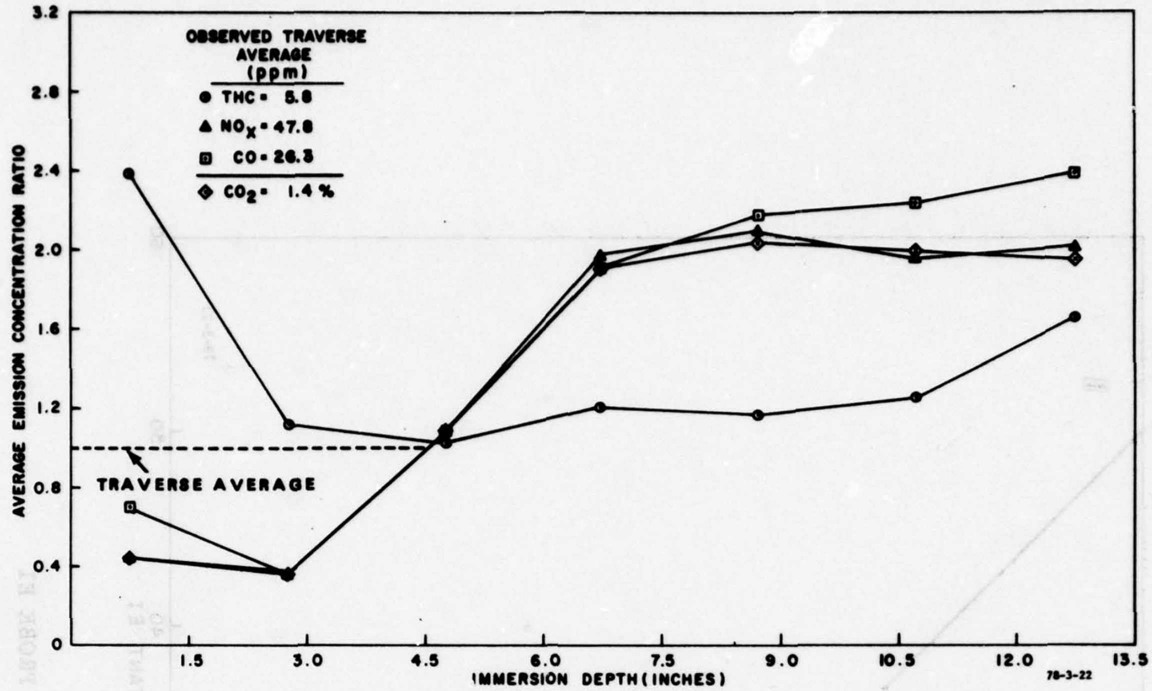


FIGURE 22(a). EMISSION CONCENTRATION DISTRIBUTION--90°--MAXIMUM CONTINUOUS POWER

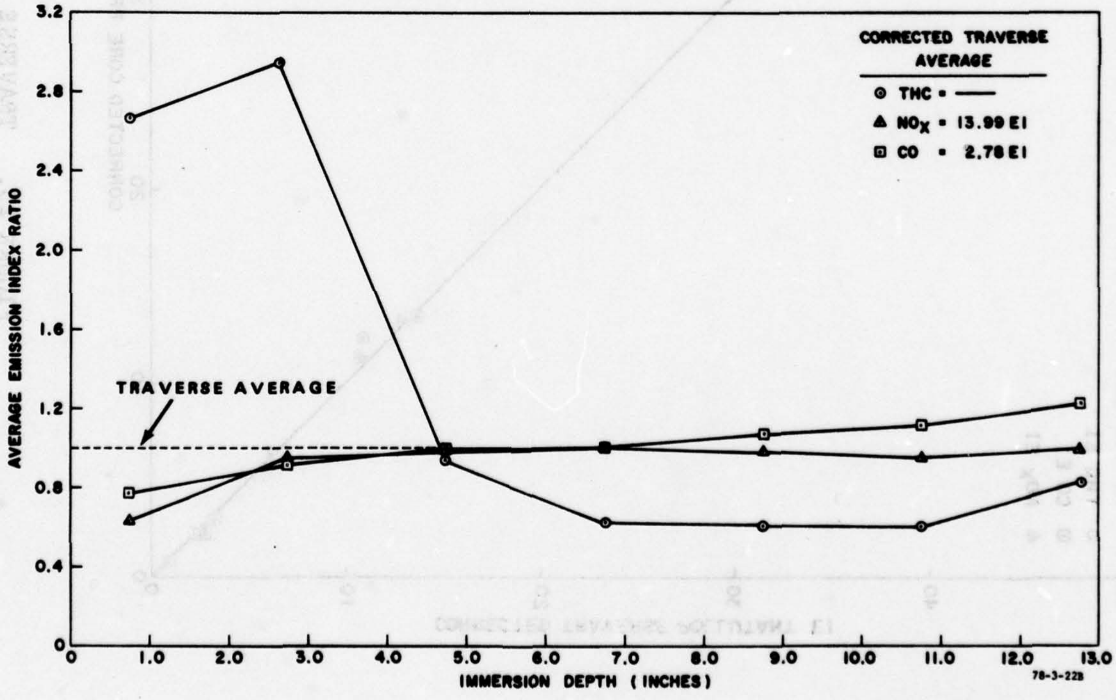


FIGURE 22(b). EMISSION INDEX DISTRIBUTION--90°--MAXIMUM CONTINUOUS POWER

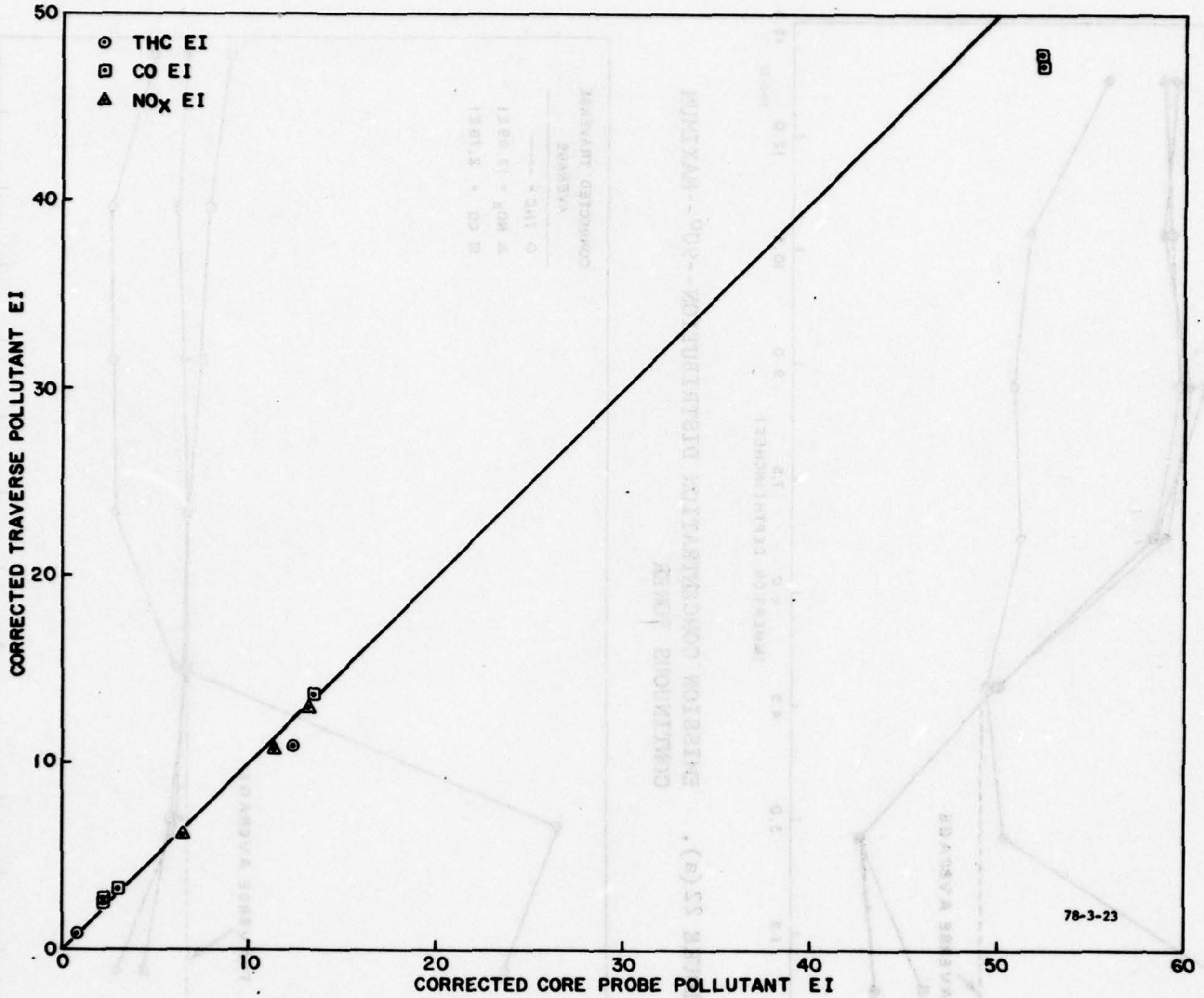


FIGURE 23. TRAVERSE AND CORE PROBE EI

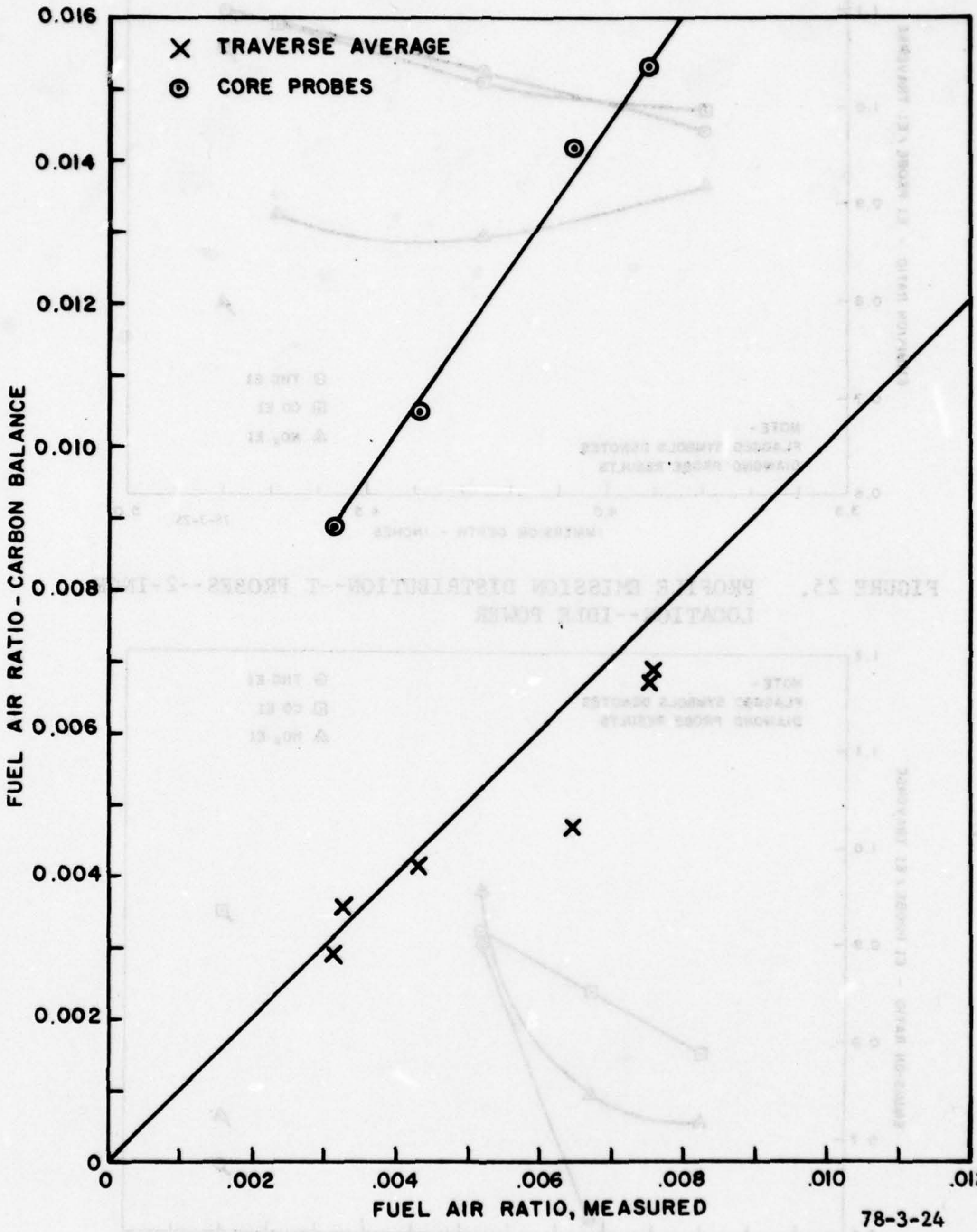


FIGURE 24. FUEL-TO-AIR RATIOS--CORE PROBES

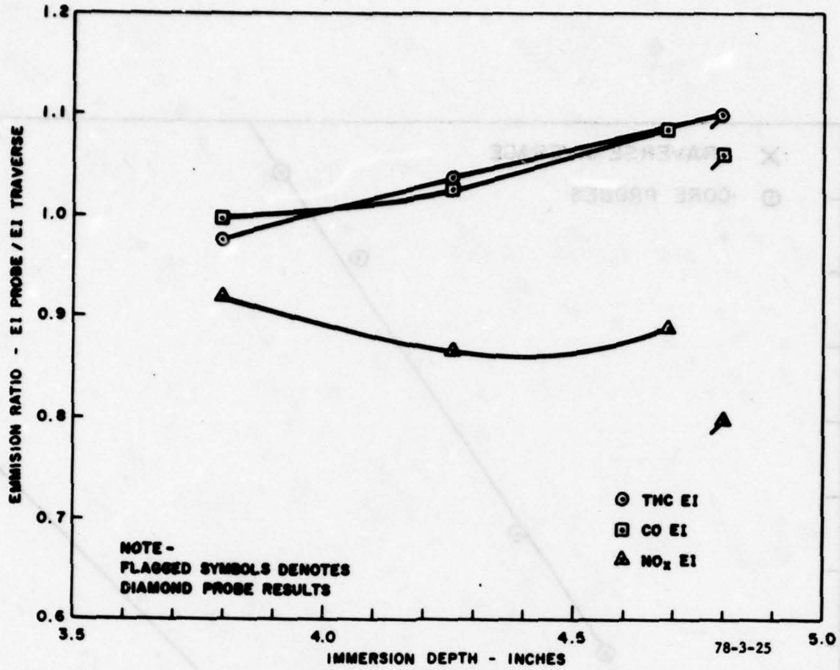


FIGURE 25. PROFILE EMISSION DISTRIBUTION--T PROBES--2-INCH LOCATION--IDLE POWER

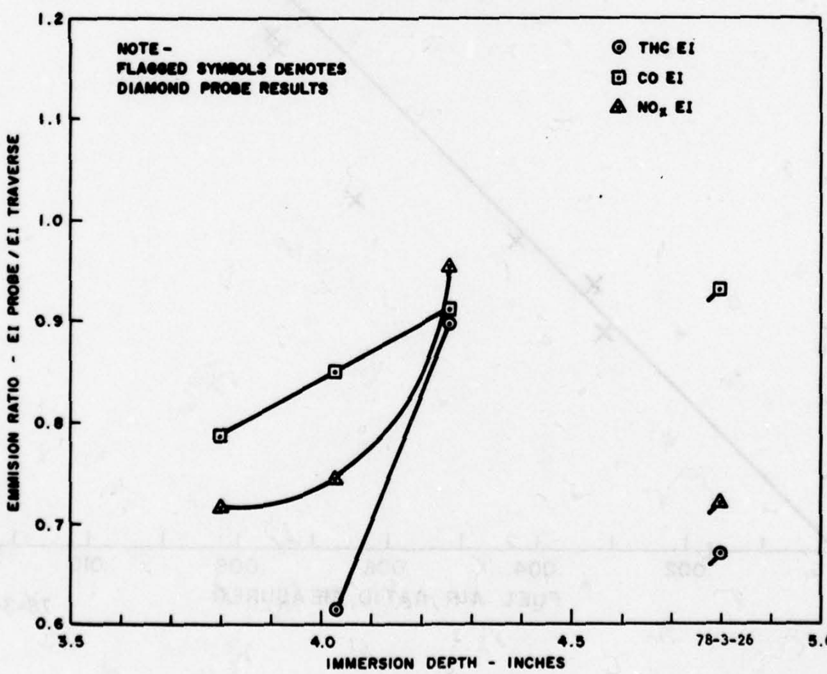


FIGURE 26. PROFILE EMISSION DISTRIBUTION--T PROBES--10-INCH LOCATION--IDLE POWER

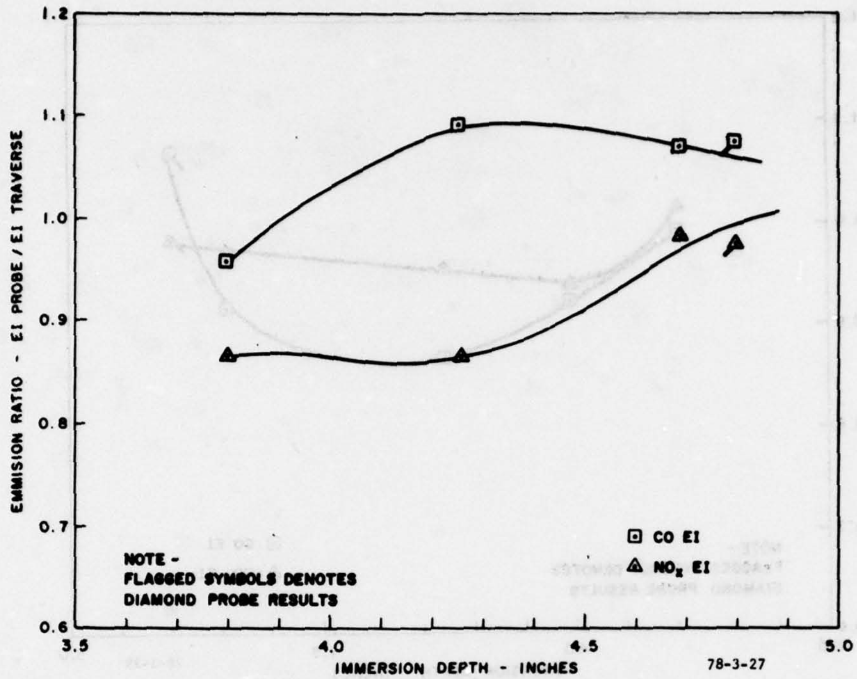


FIGURE 27. PROFILE EMISSION DISTRIBUTION--T PROBES--2-INCH LOCATION--APPROACH POWER

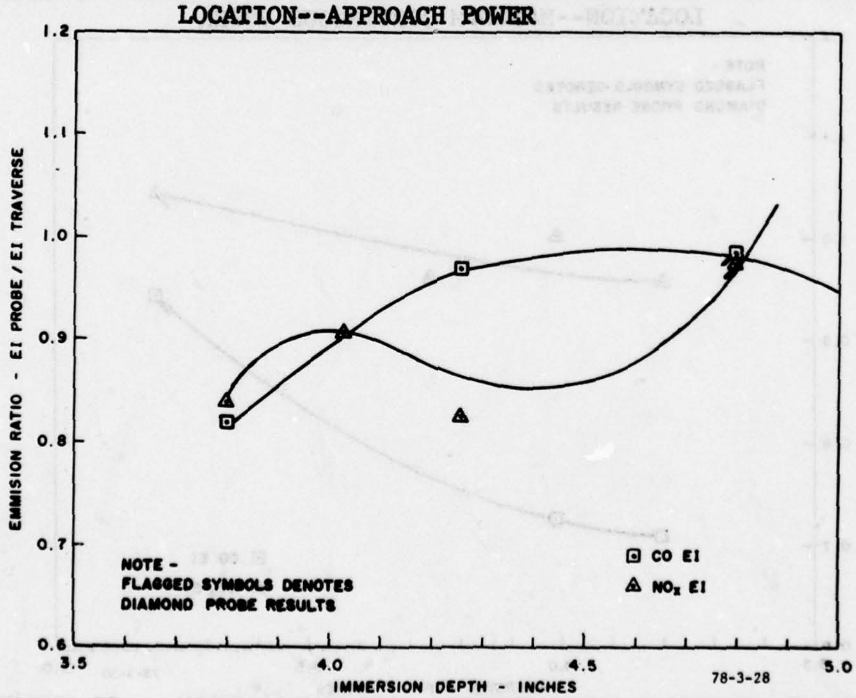


FIGURE 28. PROFILE EMISSION DISTRIBUTION--T PROBES--10-INCH LOCATION--APPROACH POWER

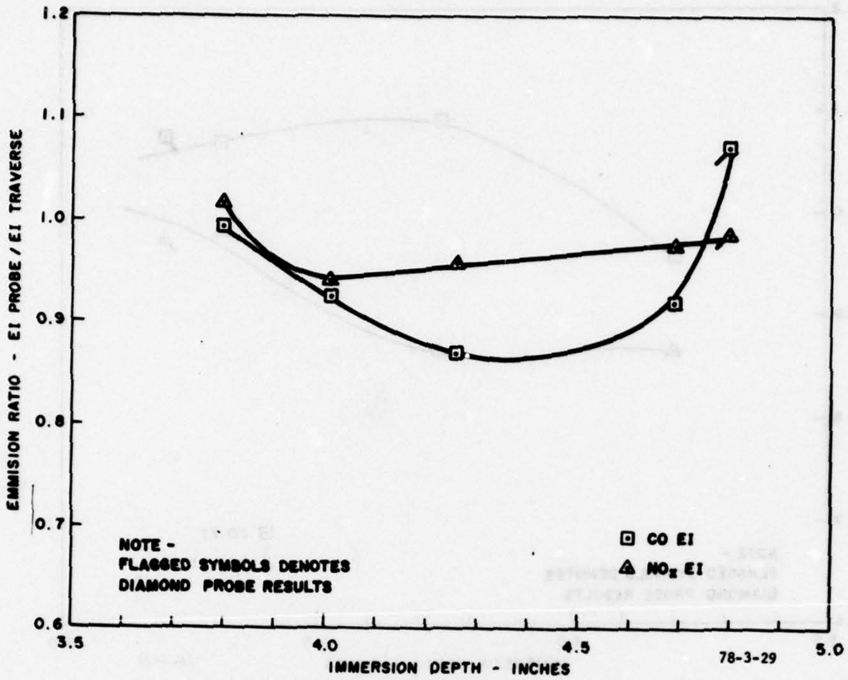


FIGURE 29. PROFILE EMISSION DISTRIBUTION--T PROBES--2-INCH LOCATION--MAXIMUM CONTINUOUS POWER

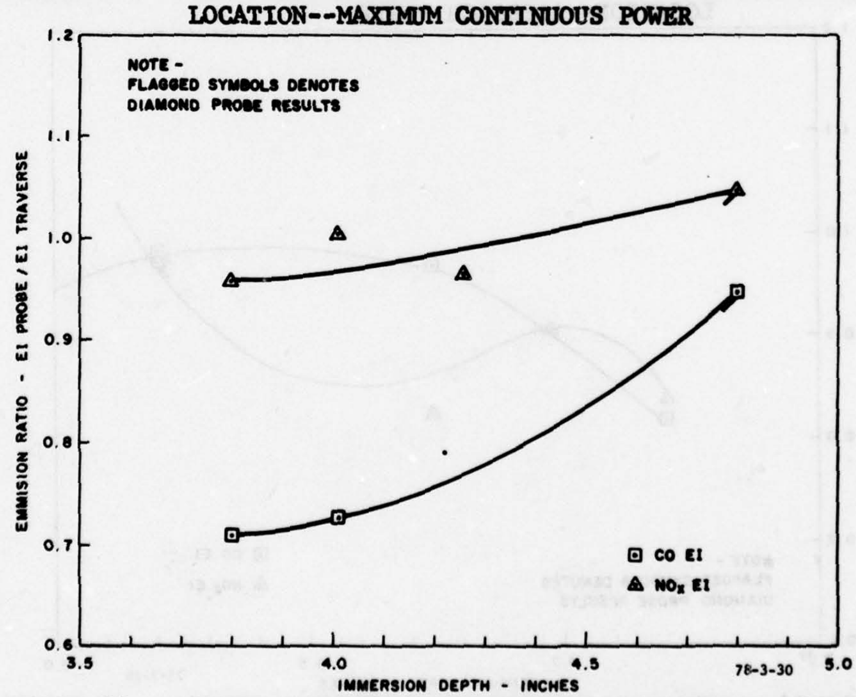


FIGURE 30. PROFILE EMISSION DISTRIBUTION--T PROBES--10-INCH LOCATION--MAXIMUM CONTINUOUS POWER

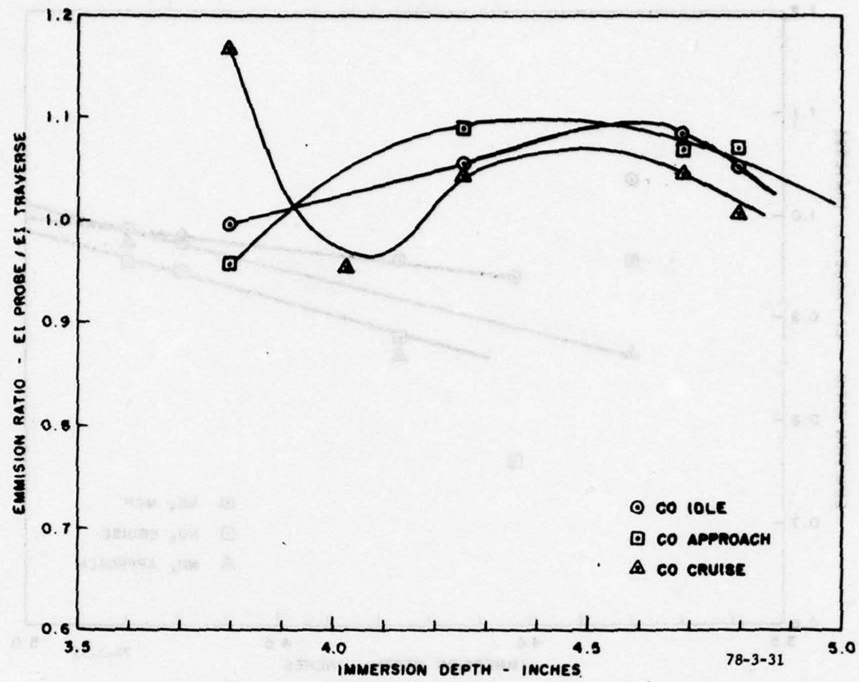


FIGURE 31. PROFILE EMMISSION DISTRIBUTION--CO--T PROBES--2-INCH LOCATION

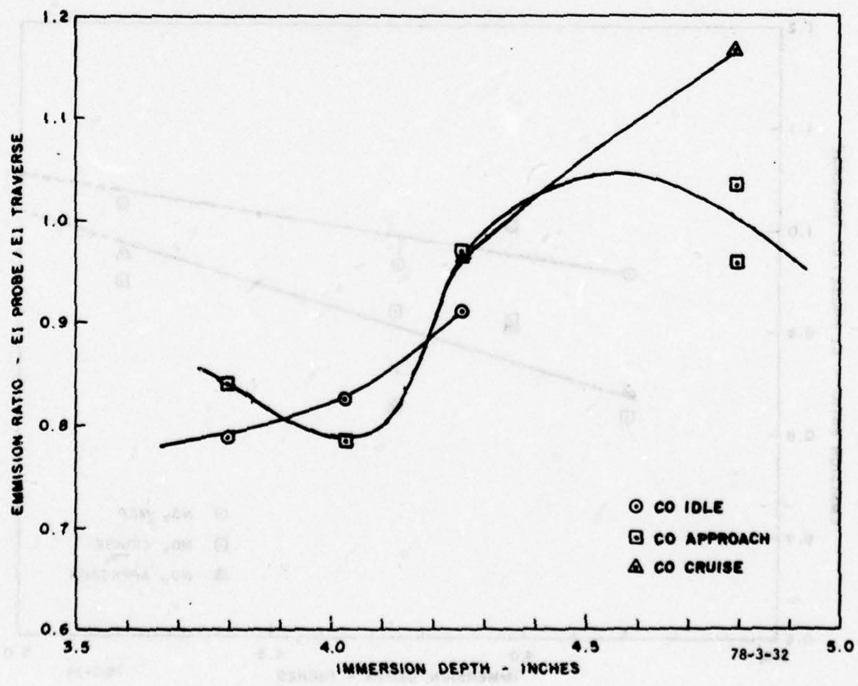


FIGURE 32. PROFILE EMISSION DISTRIBUTION--CO--T PROBES--10-INCH LOCATION

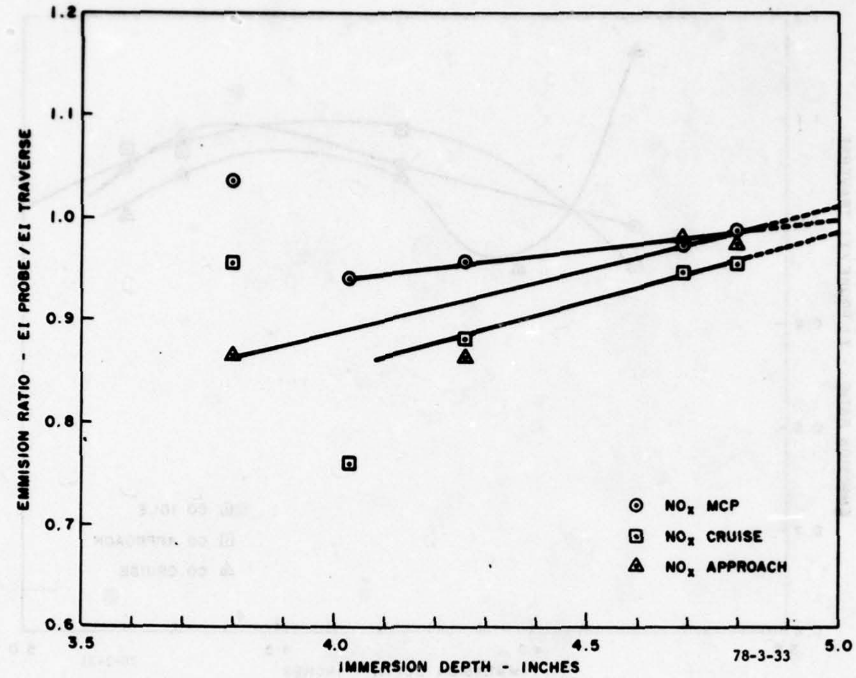


FIGURE 33. PROFILE EMISSION DISTRIBUTION--NO$_x$--T PROBES--2-INCH LOCATION

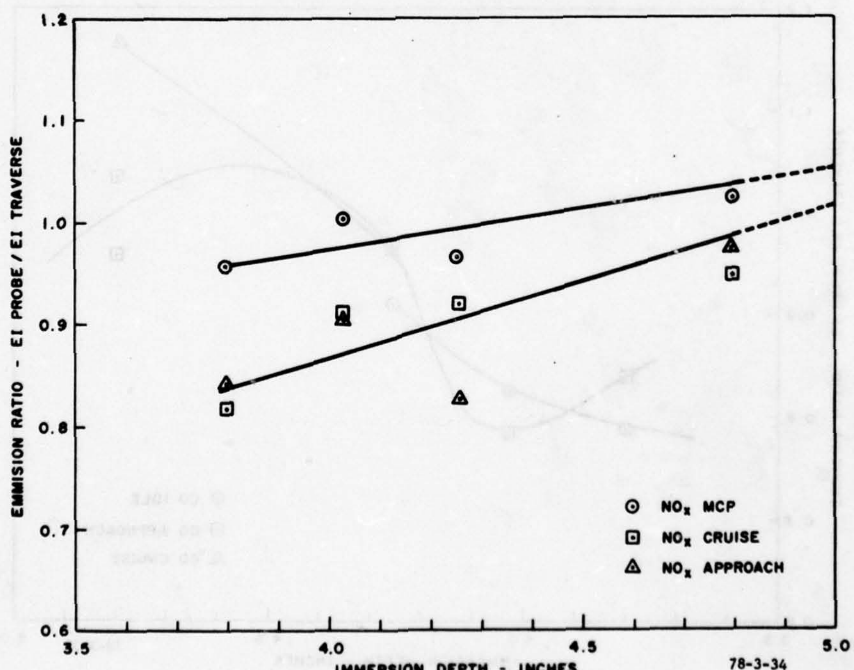


FIGURE 34. PROFILE EMISSION DISTRIBUTION--NO$_x$--T PROBES--10-INCH LOCATION

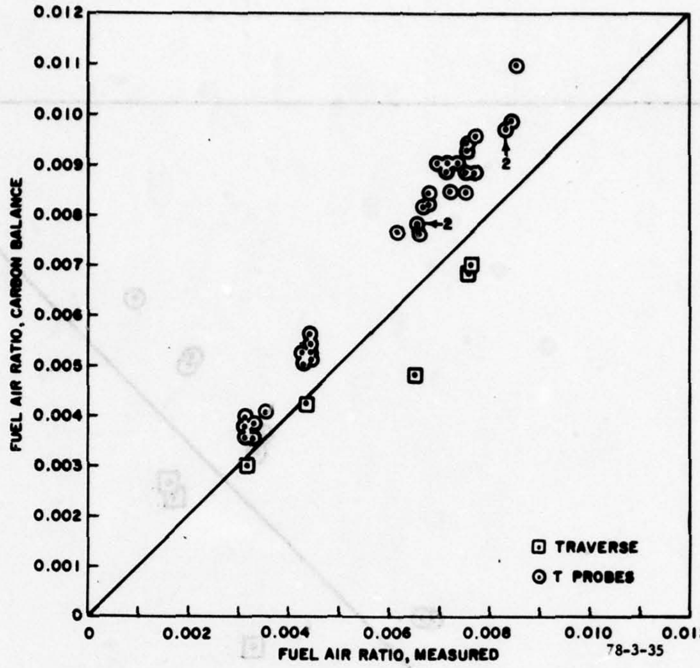


FIGURE 35. FUEL-TO-AIR RATIOS--T PROBES--63-PERCENT RADIUS--2-INCH LOCATION

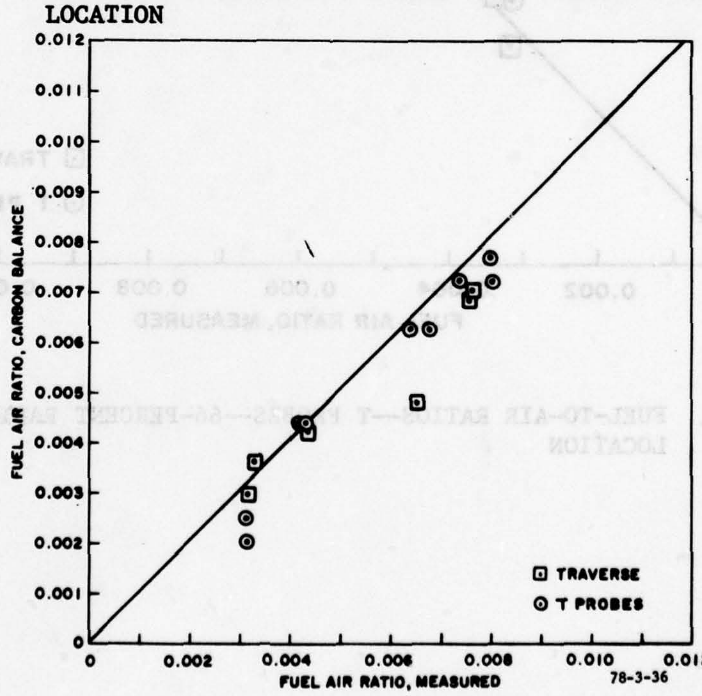


FIGURE 36. FUEL-TO-AIR RATIOS--T PROBES--70-PERCENT RADIUS--2-INCH LOCATION

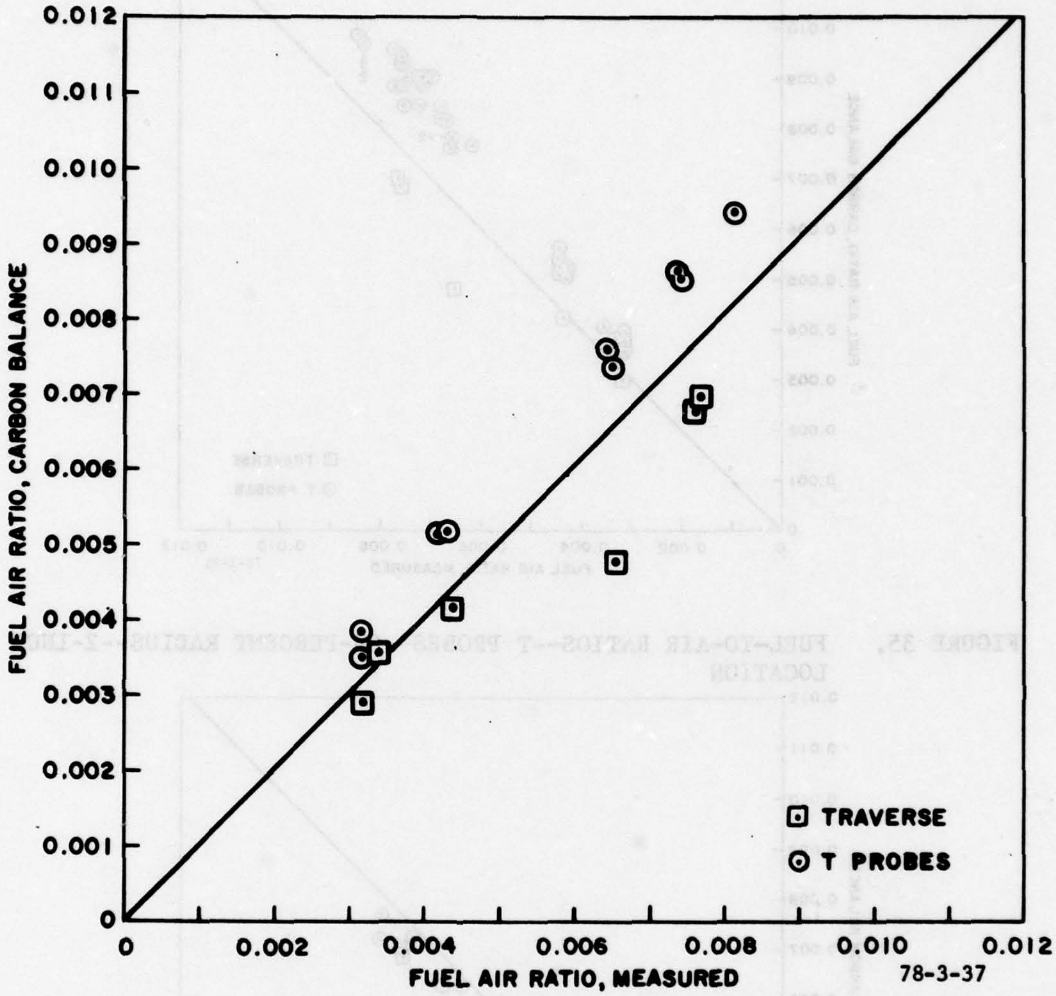


FIGURE 37. FUEL-TO-AIR RATIOS--T PROBES--66-PERCENT RADIUS--10-INCH LOCATION

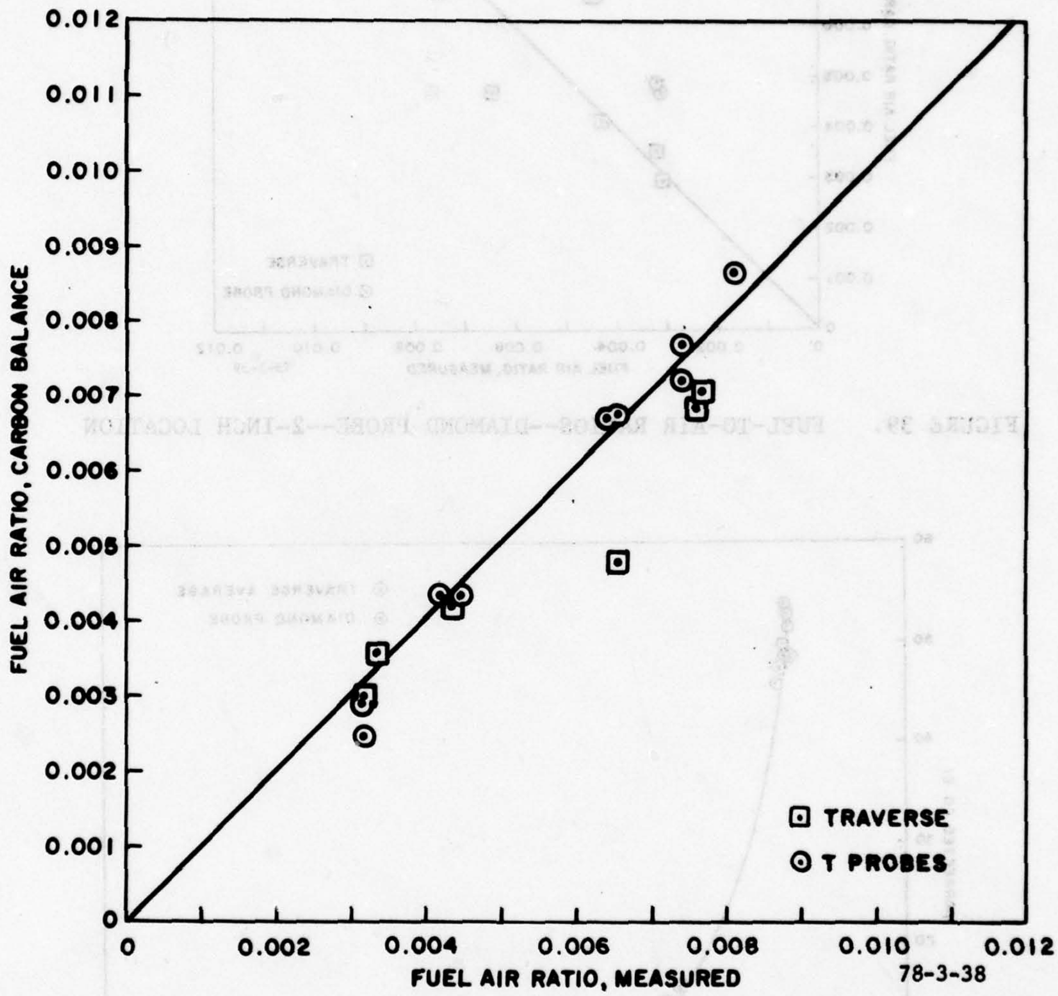


FIGURE 38. FUEL-TO-AIR RATIOS--T PROBES--70-PERCENT RADIUS--10-INCH LOCATION

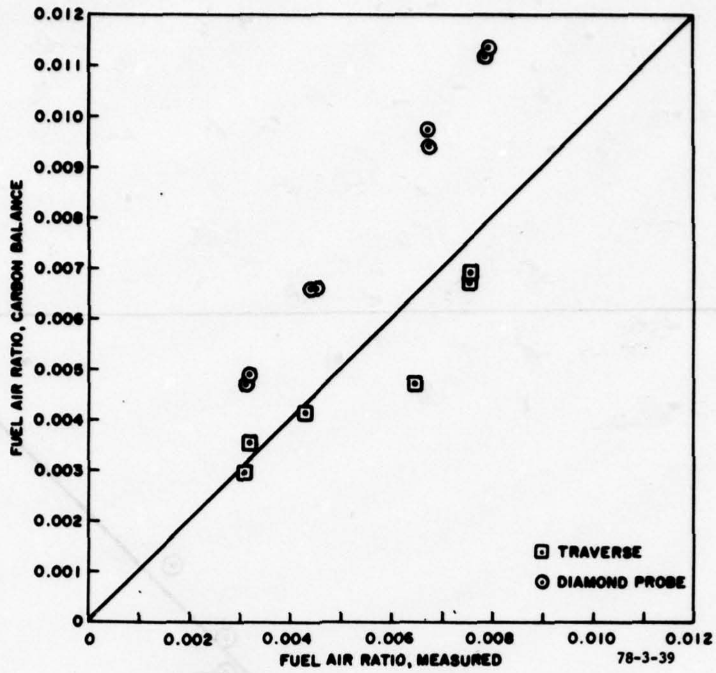


FIGURE 39. FUEL-TO-AIR RATIOS--DIAMOND PROBE--2-INCH LOCATION

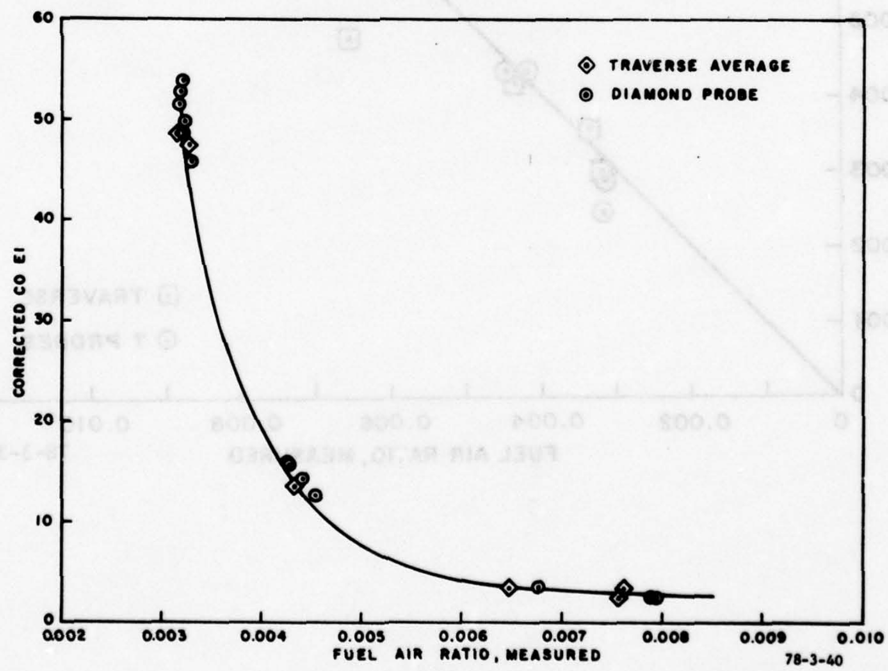


FIGURE 40. CO EI--DIAMOND PROBE--2-INCH LOCATION

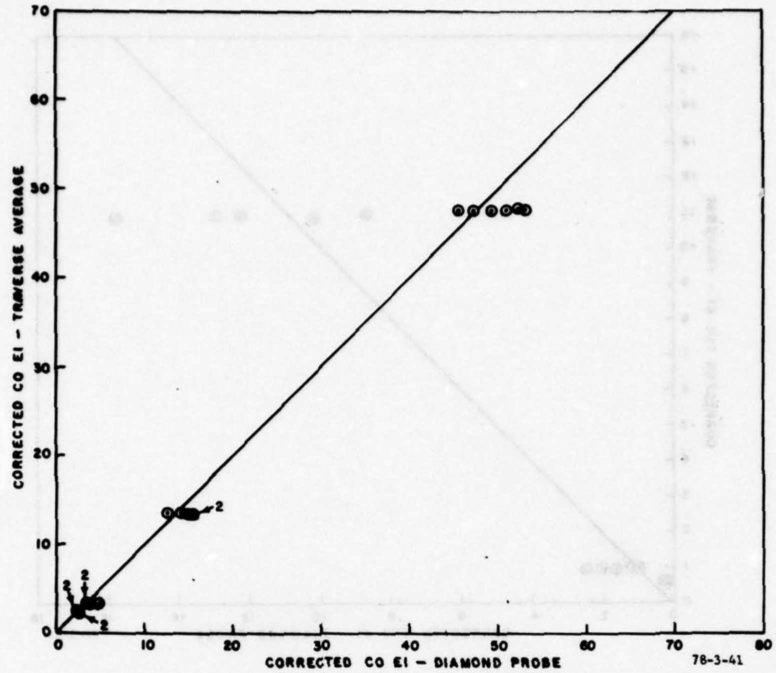


FIGURE 41. CO EI--RELATION BETWEEN TRAVERSE AND DIAMOND PROBE--2-INCH LOCATION

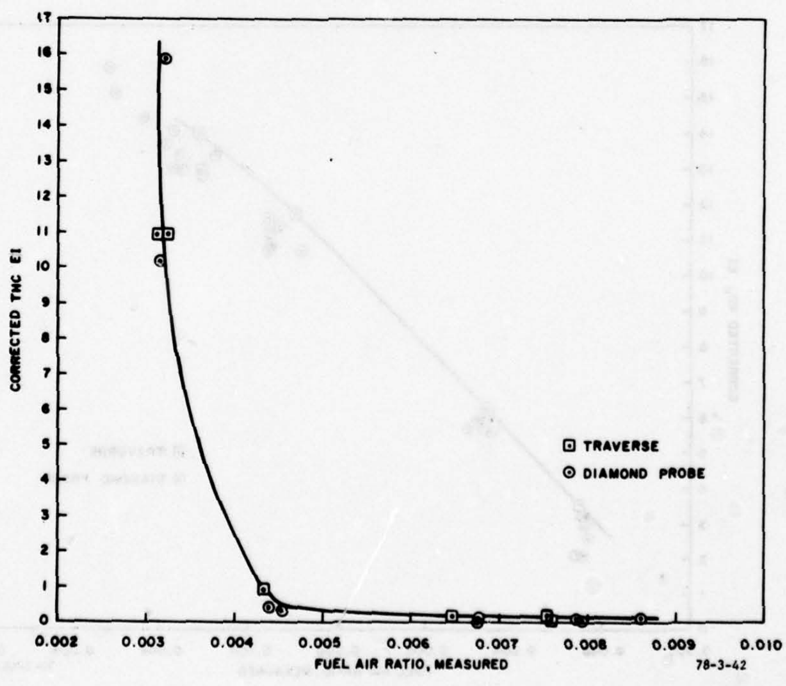


FIGURE 42. THC EI--DIAMOND PROBE--2-INCH LOCATION

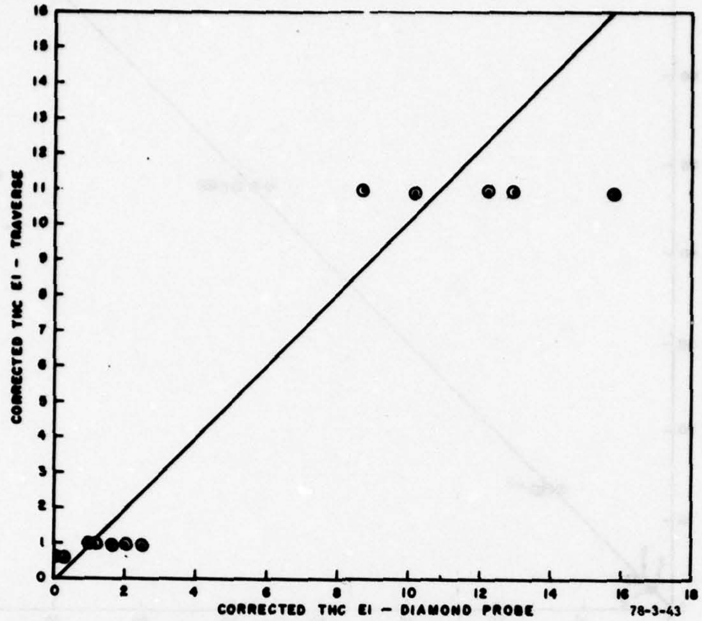


FIGURE 43. THC EI--RELATION BETWEEN TRAVERSE AND DIAMOND PROBE--2-INCH LOCATION

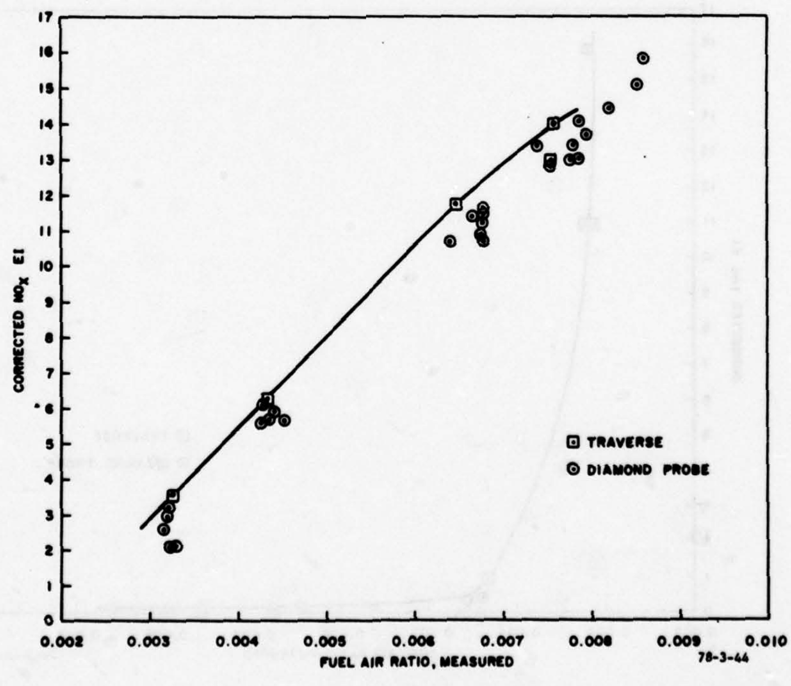


FIGURE 44. NO_x EI--DIAMOND PROBE--2-INCH LOCATION

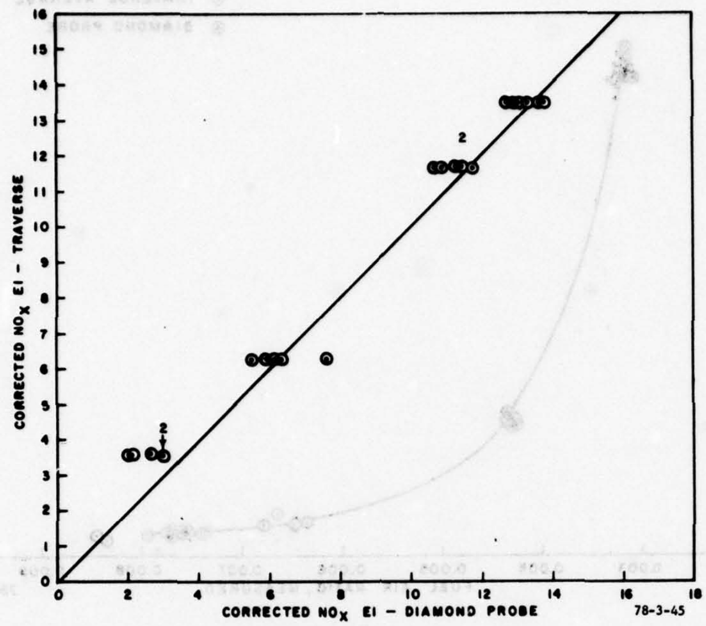


FIGURE 45. NO_x EI--RELATION BETWEEN TRAVERSE AND DIAMOND PROBE--2-INCH LOCATION

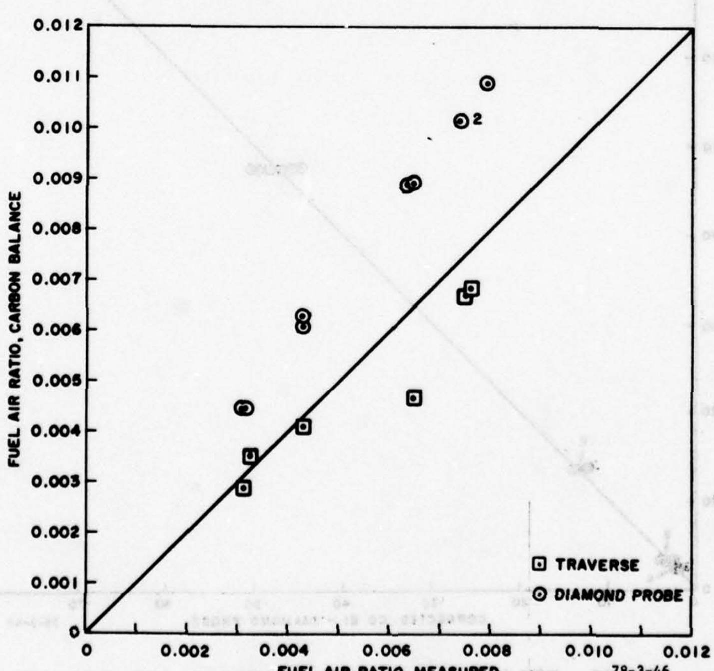


FIGURE 46. FUEL-TO-AIR RATIOS--DIAMOND PROBE--7-INCH LOCATION

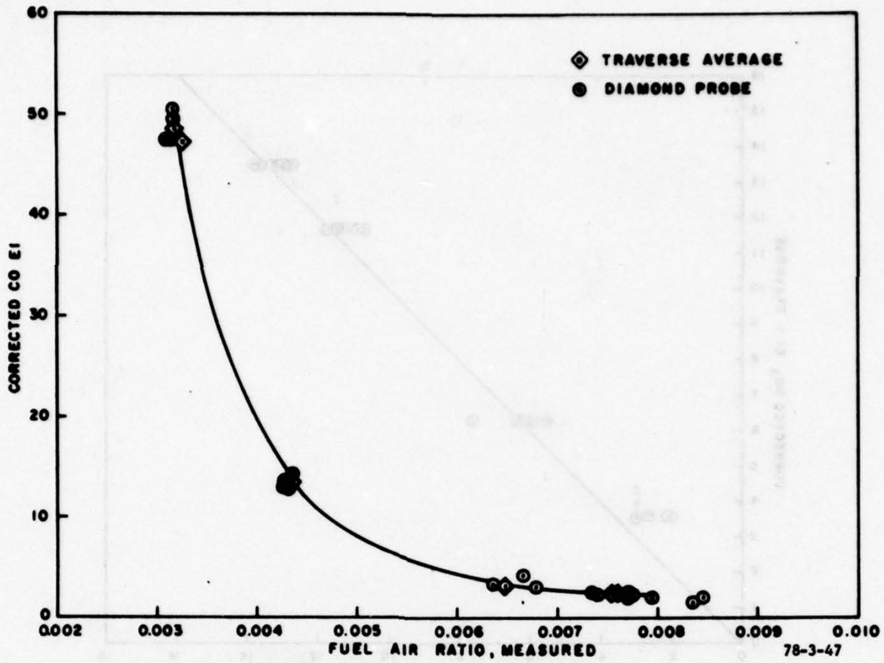


FIGURE 47. CO EI--DIAMOND PROBE--7-INCH LOCATION

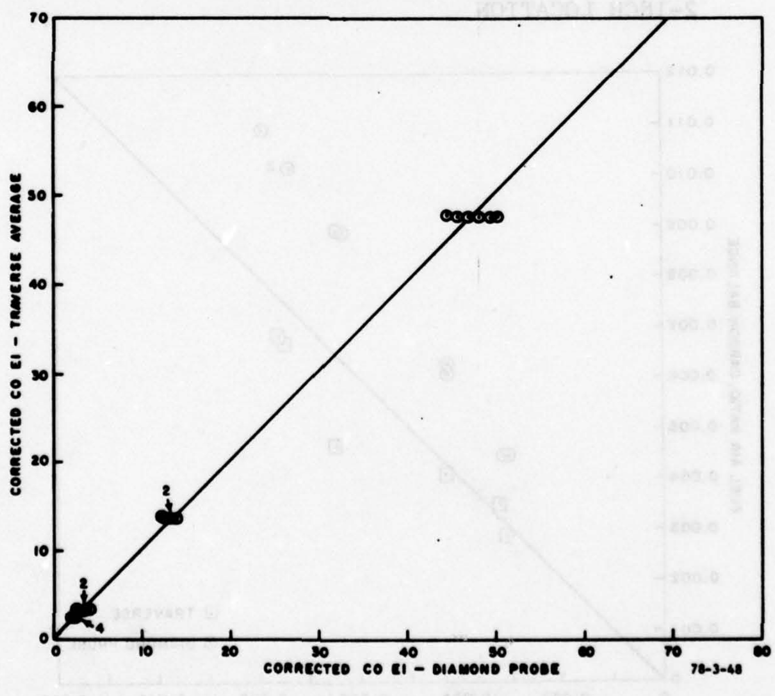


FIGURE 48. CO EI--RELATION BETWEEN TRAVERSE AND DIAMOND PROBE--7-INCH LOCATION

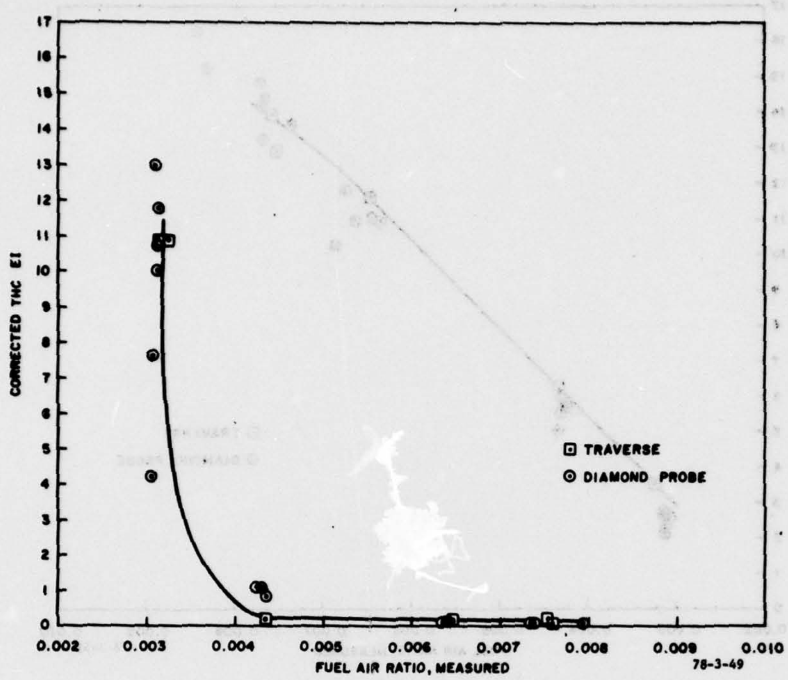


FIGURE 49. THC EI--DIAMOND PROBE--7-INCH LOCATION

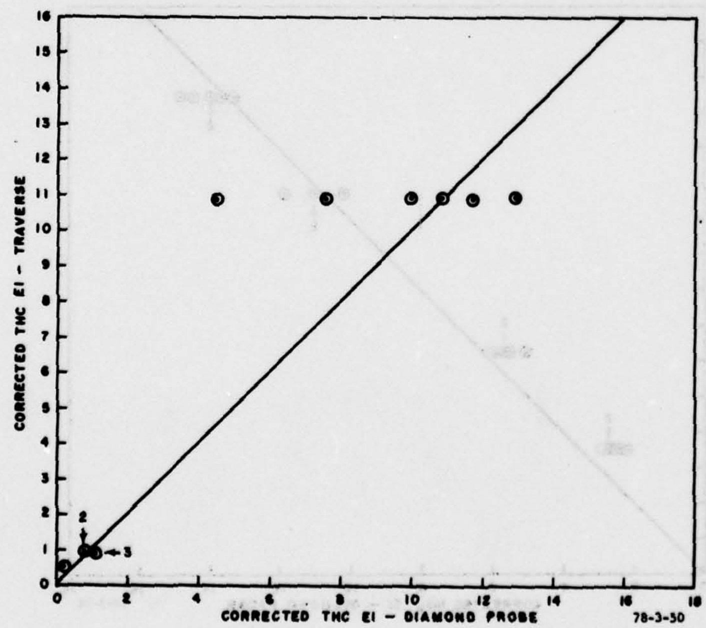


FIGURE 50. THC EI--RELATION BETWEEN TRAVERSE AND DIAMOND PROBE--
7-INCH LOCATION

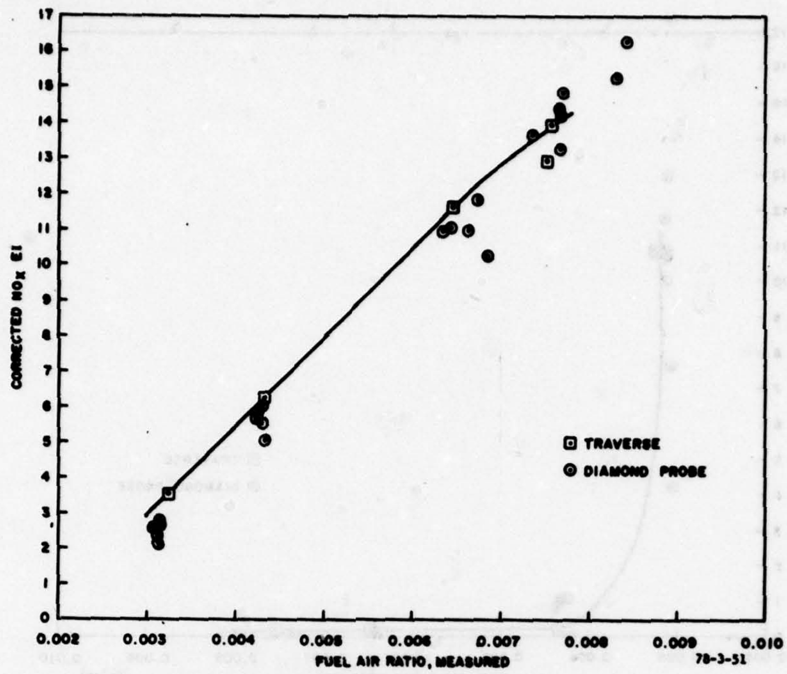


FIGURE 51. NO_x EI--DIAMOND PROBE--7-INCH LOCATION

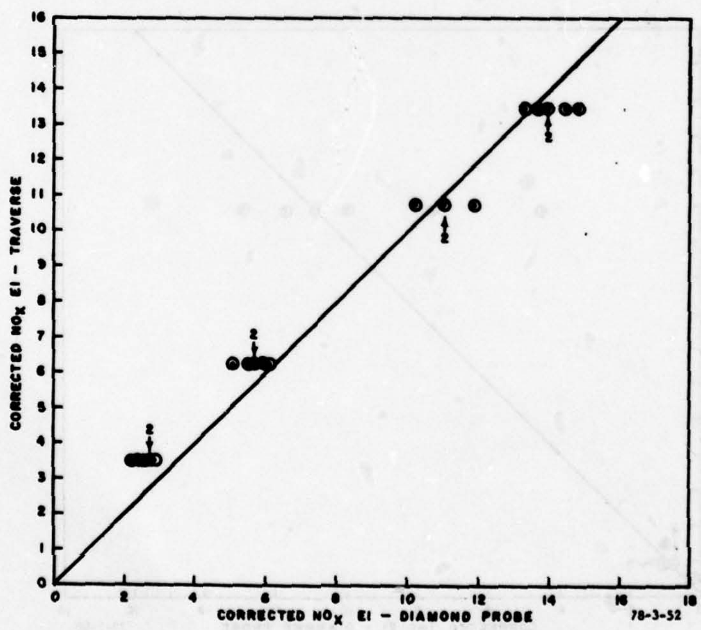


FIGURE 52. NO_x EI--RELATION BETWEEN TRAVERSE AND DIAMOND PROBE--7-INCH LOCATION

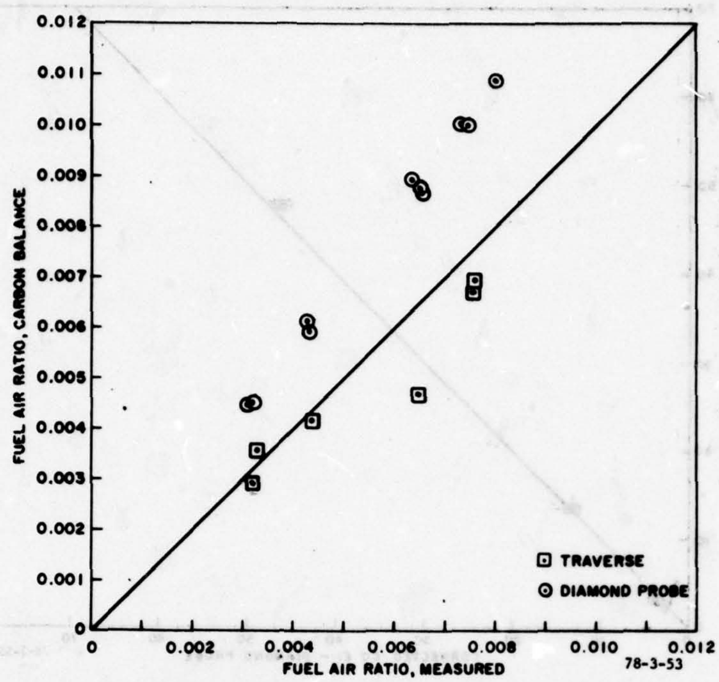


FIGURE 53. FUEL-TO-AIR RATIOS--DIAMOND PROBE--10-INCH LOCATION

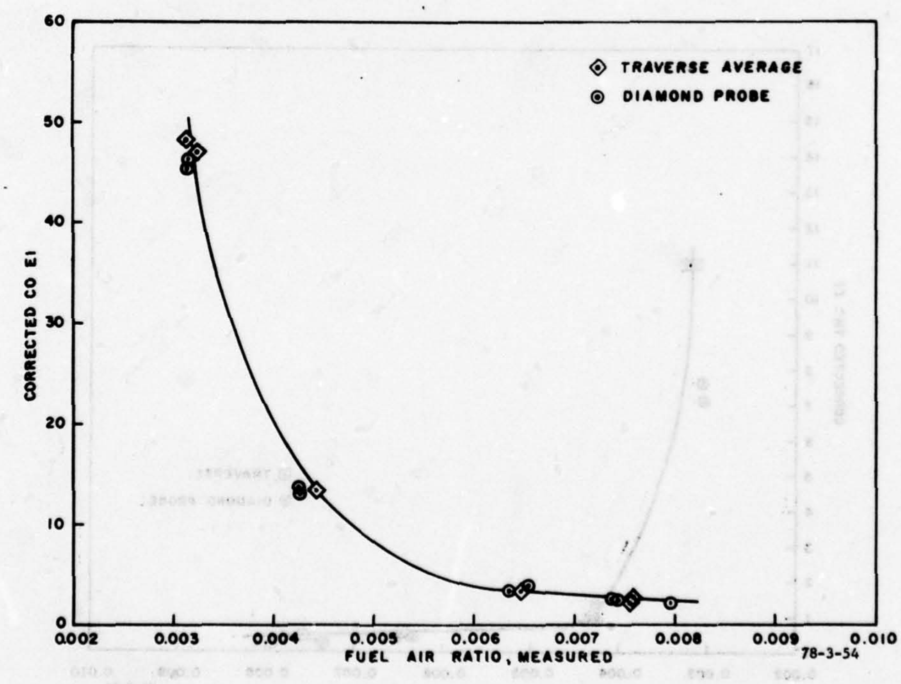


FIGURE 54. CO EI--DIAMOND PROBE--10-INCH LOCATION

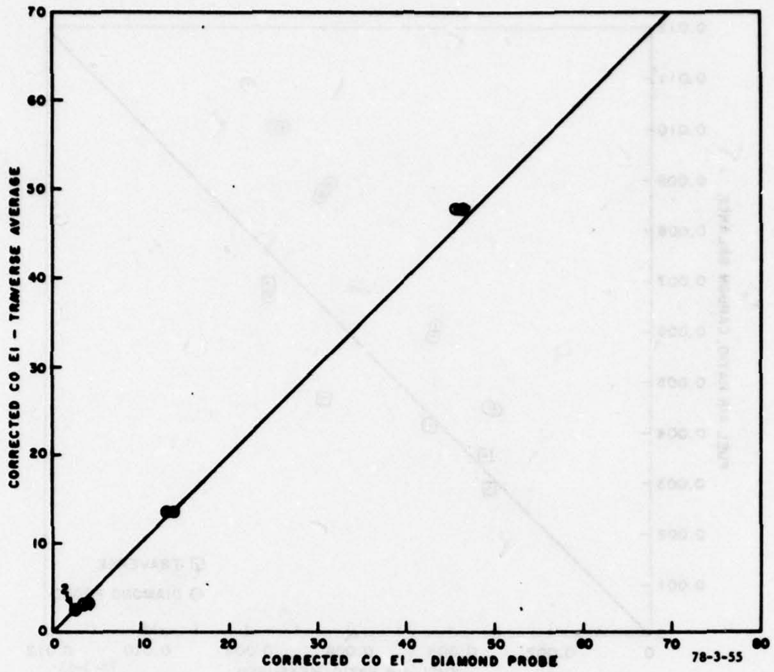


FIGURE 55. CO EI--RELATION BETWEEN TRAVERSE AND DIAMOND PROBE--10-INCH LOCATION

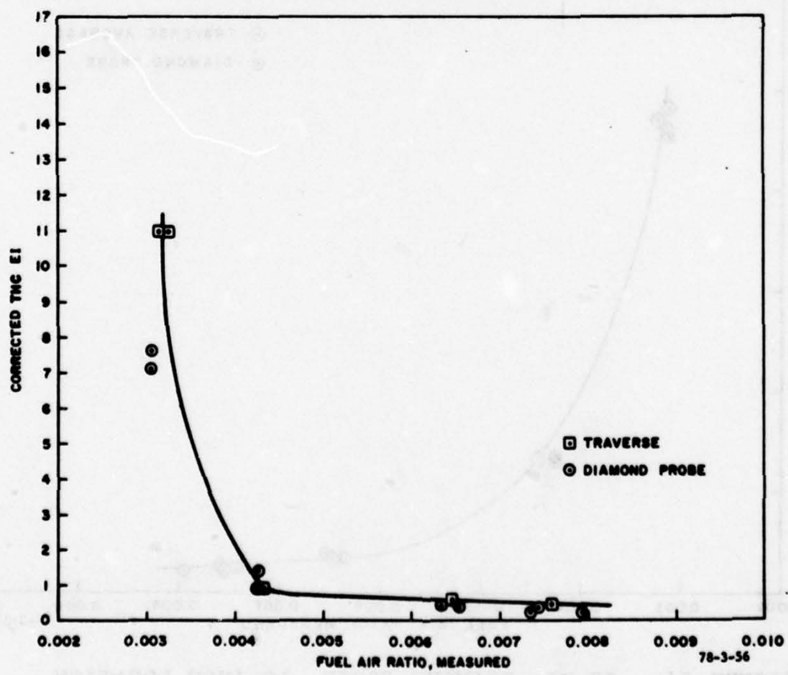


FIGURE 56. THC EI--DIAMOND PROBE--10-INCH LOCATION

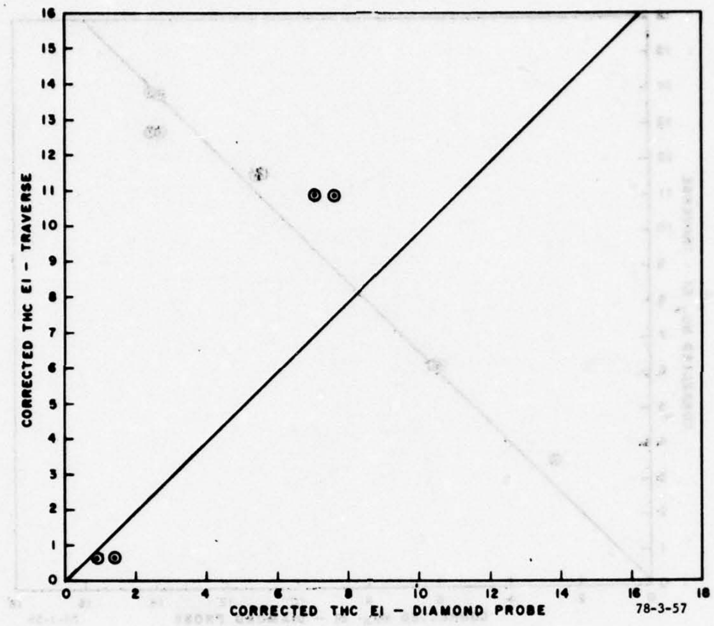


FIGURE 57. THC EI--RELATION BETWEEN TRAVERSE AND DIAMOND PROBE--10-INCH LOCATION

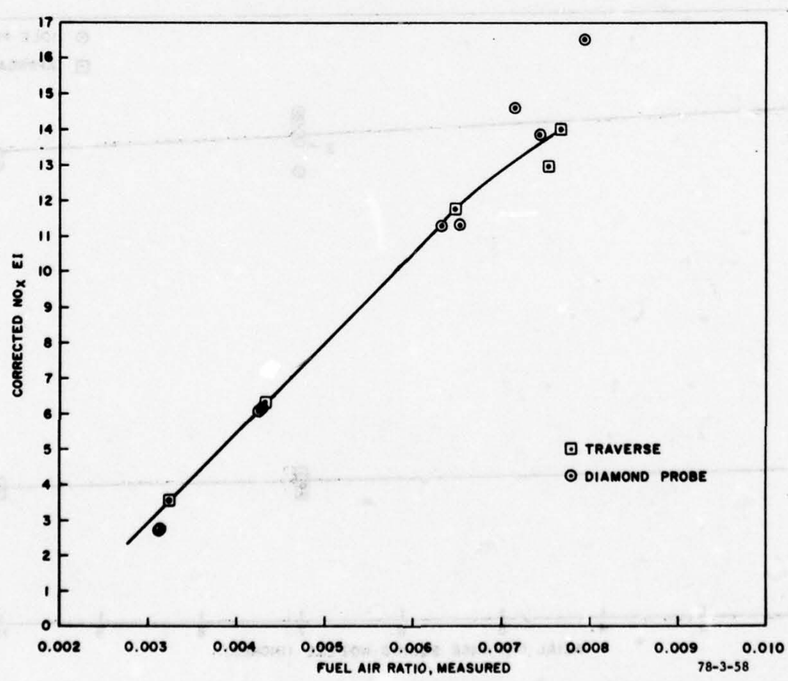


FIGURE 58. NO_x EI--DIAMOND PROBE--10-INCH LOCATION

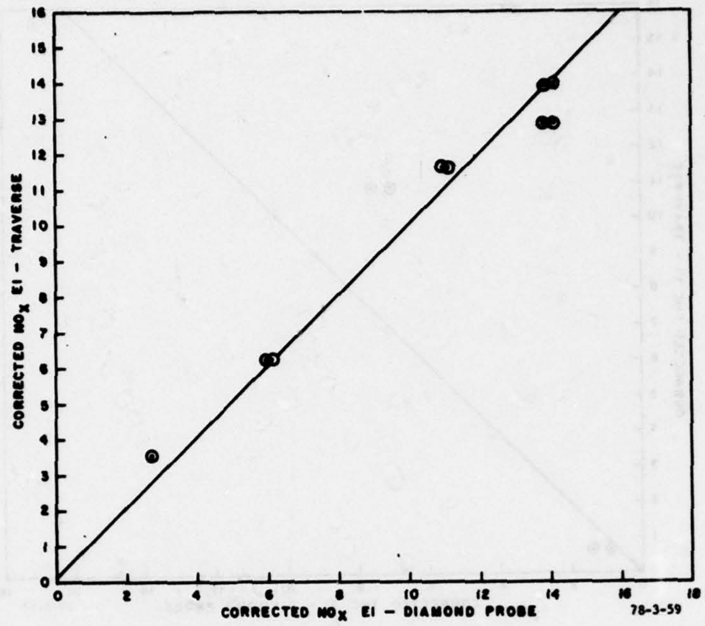


FIGURE 59. NO_x EI--RELATION BETWEEN TRAVERSE AND DIAMOND PROBE--10-INCH LOCATION

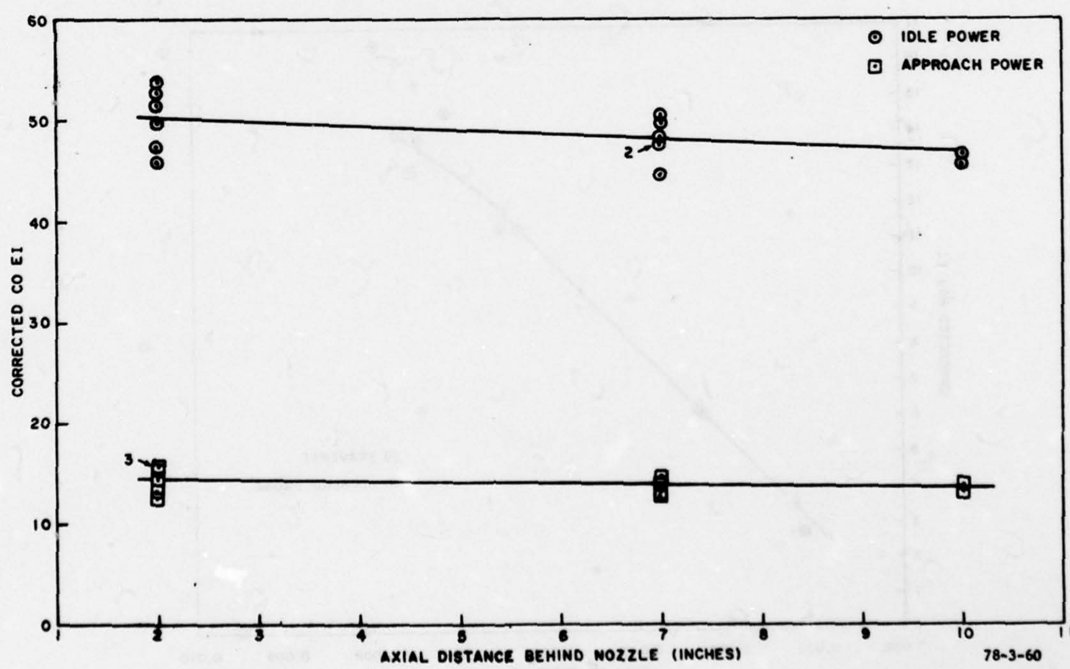


FIGURE 60. EFFECT OF DIAMOND PROBE LOCATION--CO EI

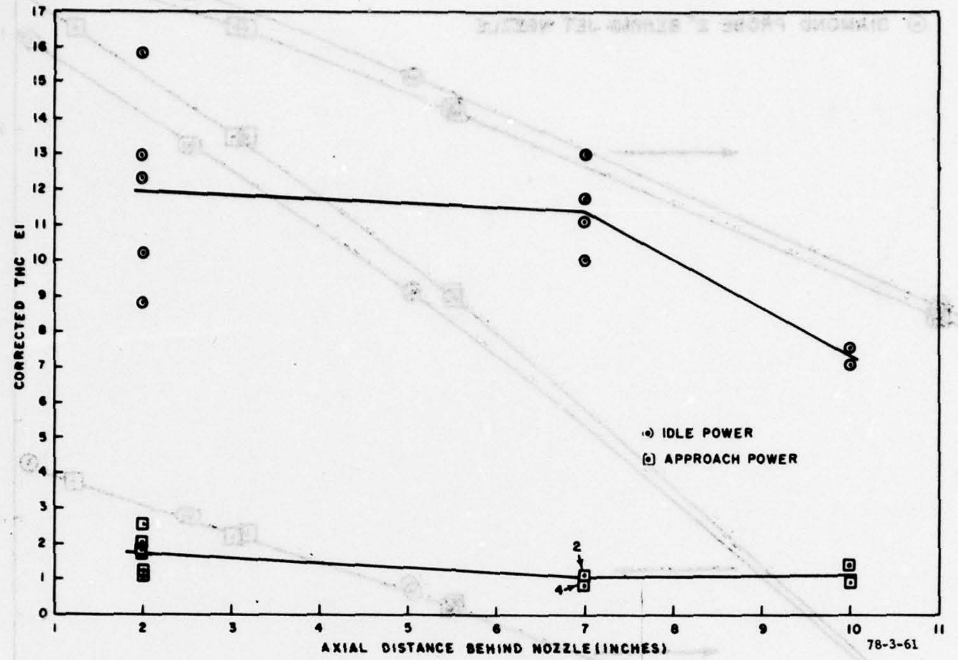


FIGURE 61. EFFECT OF DIAMOND PROBE LOCATION--THC EI

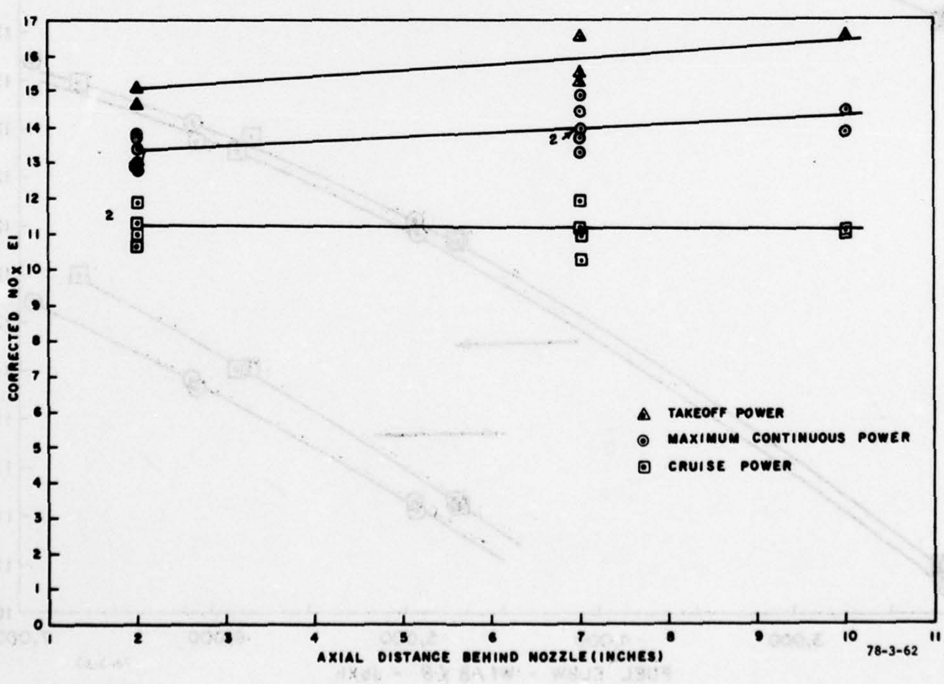


FIGURE 62. EFFECT OF DIAMOND PROBE LOCATION--NO_x EI

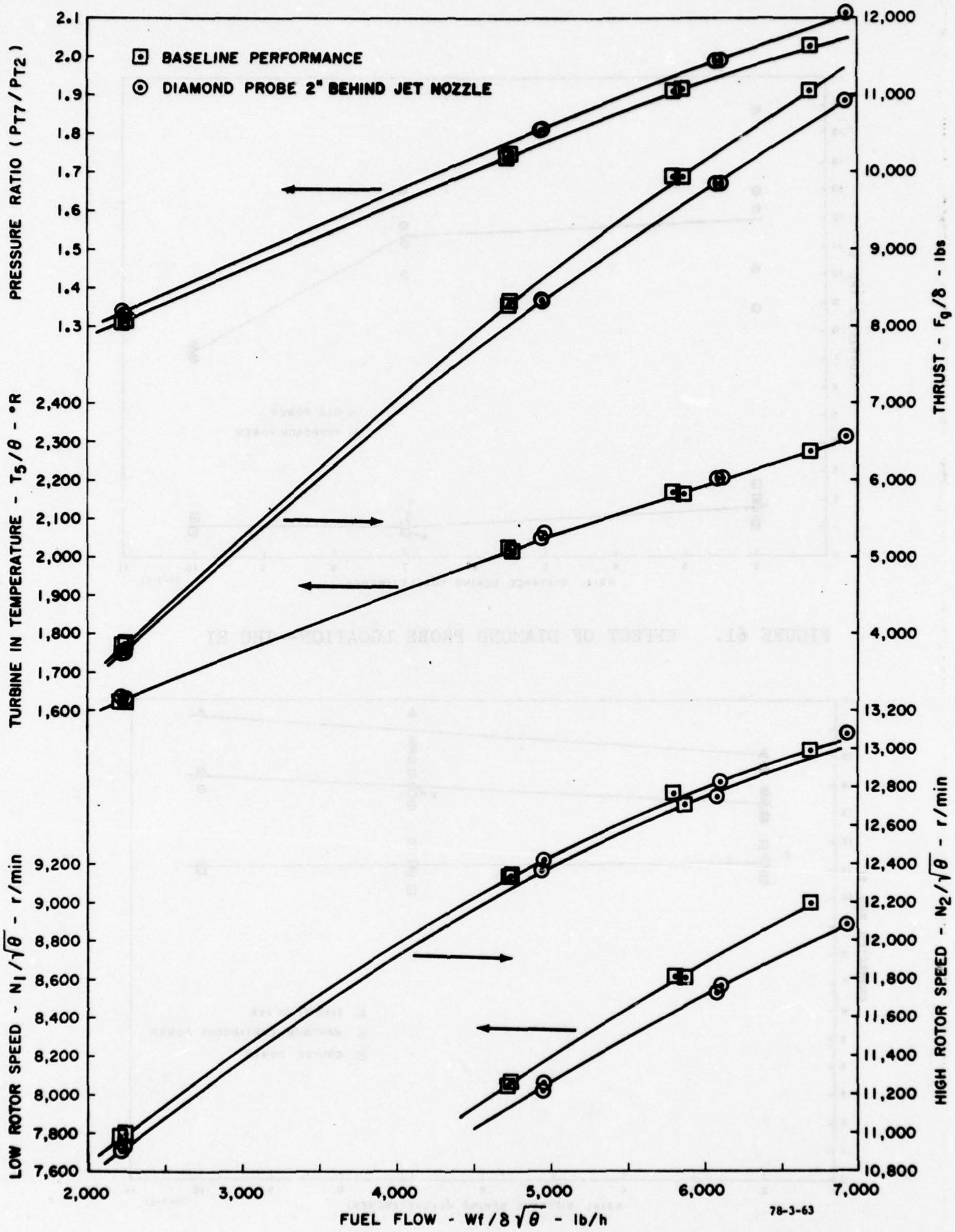


FIGURE 63. EFFECT OF DIAMOND PROBE ON ENGINE PERFORMANCE--2-INCH LOCATION

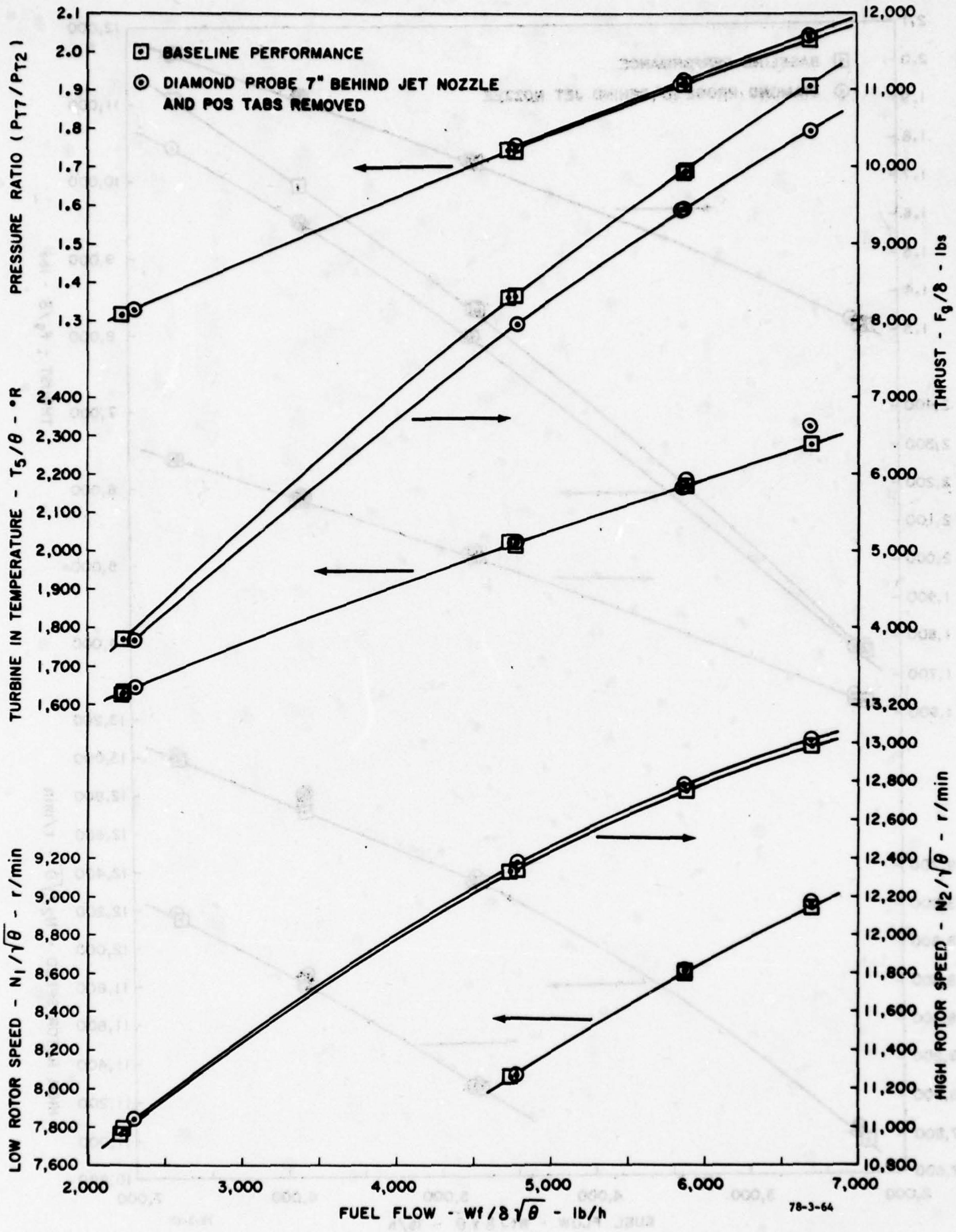


FIGURE 64. EFFECT OF DIAMOND PROBE ON ENGINE PERFORMANCE--7-INCH LOCATION

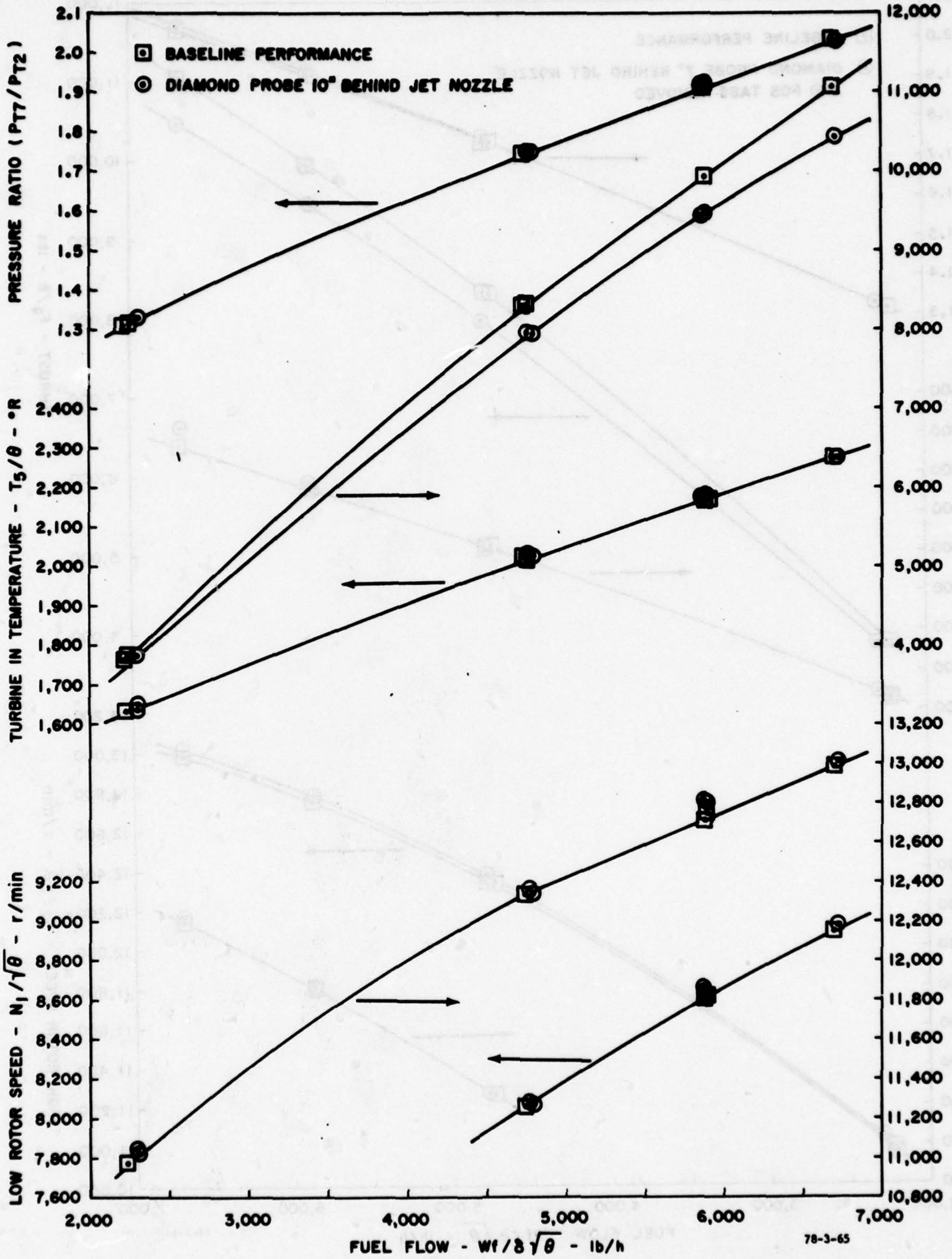


FIGURE 65. EFFECT OF DIAMOND PROBE ON ENGINE PERFORMANCE--10-INCH LOCATION

APPENDIX A

ENGINE PERFORMANCE AND TRAVERSE EMISSION INDICES

TABLE A-1. ENGINE PERFORMANCE AND TRAV

Power	Probe	Probe Axial Pos. In.	Run No.	t2 °F	Spec. H Grains H2O lb/Dry Air	P2 in. Hg. A	EPR	Air-Flow lb/sec.	Fuel Flow lb/hr.	Thrust lb	t3 °F	P3 in. Hg. A	CO_2 Perce
Idle	Nozzle Traverse	2	14	41	23.33	30.24	1.079	76.2	877	1065	222	80.8	0.58
Idle	Nozzle Traverse	2	264	29	20.78	29.77	1.084	78.1	913	1132	209	-	0.69
Approach	Nozzle Traverse	2	15	40.36	29.91	30.17	1.312	143.8	2242	3812	415	189.1	0.86
Cruise	Nozzle Traverse	2	16	51.4	46	29.72	1.737	204.0	4786	8263	621	334.5	0.97
MCP	Nozzle Traverse	2	17	51.7	49.0	29.55	1.906	218.3	5879	9898	681	384.2	1.39
MCP	Nozzle Traverse	2	266	31	17.94	30.14	1.905	218.5	5972	9909	628	-	1.43
Idle	Core	-	14	41	23.33	30.24	1.079	76.2	877	1065	222	80.8	1.752
Approach	Core	-	15	40.3	29.91	30.17	1.312	143.8	2242	3812	415	189.1	2.145
Cruise	Core	-	16	51.4	46	29.72	1.737	204.0	4786	8263	621	334.5	2.910
MCP	Core	-	17	51.7	49.0	29.55	1.906	218.3	5879	9898	681	384.2	3.327

TRAVERSE EMISSION INDICES

CO_2 Percent	CO EI	THC EI	NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} \times 100}{F/A_M}$ (%)
0.58	52.79	13.49	-	48.39	10.91	-	0	0	-	.00292	.00314	93.0
0.69	54.67	15.66	2.66	47.12	10.90	3.57	0	0	0	.00356	.00325	109.5
0.86	15.75	1.78	5.00	13.62	0.93	6.26	0	0	0	.00413	.00432	95.6
0.97	3.44	0.63	9.73	3.17	-	11.71	0	-	0	.0047	.00647	72.6
1.39	2.68	0.87	10.78	2.50	-	12.93	0	-	0	.0067	.00753	89.0
1.43	3.66	0.46	10.94	2.78	-	13.99	0	-	0	.00686	.00759	90.4
1.752	57.06	15.32	2.49	52.30	12.39	3.08	108.1	113.6	-	.00888	.00314	282.8
2.145	15.56	1.50	5.09	13.46	0.83	6.37	98.8	89.2	101.8	.01052	.00432	243.5
2.910	3.27	.22	9.46	3.01	-	11.39	95.1	-	97.3	.01420	.00647	219.5
3.327	2.42	.43	10.93	2.26	-	13.11	90.3	-	101.4	.01628	.00753	216.2

APPENDIX B

T PROBES - ENGINE PERFORMANCE AND EMISSION DATA BASE

TABLE B-1. T PROBES -- ENGINE PERFORMANCE AND EMISSION INDICES AT

Probe	Probe Axial Pos. Inch	Engine Power	EPR	Run No.	t2 °F	Spec. H Grains H2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Sec.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI	NO_x EI
Nozzle Traverse	2	Idle	1.079	14	41	23.33	30.24	76.2	877	1065	222	80.8	52.79	13.49	-
Nozzle Traverse	2	Idle	1.084	264	29	20.78	29.77	78.1	913	1132	209	-	54.67	15.66	2.66
T	2	Idle	1.076	21	17	10.72	30.41	72.7	834	945	165	77.91	60.84	26.16	1.75
T	2	Idle	1.082	24	35	24.6	30.41	77.5	897	1095	180	82.41	59.34	22.46	2.80
T	2	Idle	1.083	30	37	26.89	30.21	77.8	914	1066	230	81.21	55.93	18.08	2.53
T	2	Idle	1.080	34	65	74.02	29.85	77.6	976	1066	250	79.85	47.42	13.50	1.61
T	2	Idle	1.082	39	39	20.59	29.90	78.8	896	1093	230	80.90	54.13	15.84	1.78
T	2	Idle	1.084	47	38	18.79	29.85	80.7	888	1085	217	80.85	59.95	12.69	3.03
T	2	Idle	1.087	53	31	10.72	29.98	80.7	907	1110	193	80.98	67.45	18.52	2.79
T	2	Idle	1.080	56	36	23.57	29.89	79.0	892	1154	215	80.89	52.81	16.57	1.67
T	2	Idle	1.084	62	38	21.54	29.93	-	882	1112	197	80.43	52.72	14.95	2.78
T	2	Idle	1.046	72	59	28.08	30.28	76.0	895	1050	240	79.28	55.47	13.12	3.34
T	2	Idle	1.079	73	76	74.02	29.83	77.5	902	1036	280	78.83	44.46	11.85	2.83
T	2	Idle	1.081	80	69	74.02	29.77	79.2	915	1089	265	78.77	50.85	12.41	4.24
T	2	Idle	1.082	81	52	33.27	29.77	78.1	897	1098	-	79.77	54.04	17.73	3.12
T	2	Idle	1.083	90	55	22.54	30.05	77.7	882	1078	-	80.05	54.17	14.93	1.34
T	2	Idle	1.083	98	52	22.54	30.04	78.8	886	1068	225	80.04	58.04	15.99	3.34
N													15	15	15
S													5.6	3.9	0.8
$\bar{X}$													55.17	16.32	2.50

T IDLE POWER-- 63 PERCENT RADIUS

CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} \times 100}{F/A_M}$ (%)
48.39	10.91		0	0	0	.00292	.00314	
47.12	10.90	3.57	0	0	0	.00356	.00325	109.5
49.15	15.55	2.55				-	.00322	
52.76	16.86	3.62				.00341	.00321	106.2
50.24	13.92	3.23				.00378	.00349	115.9
48.75	14.44	1.88				.00395	.00316	114.5
49.37	12.65	2.19				.00358	.00305	113.3
54.12	9.89	3.76				.00368	.00312	120.6
58.74	13.22	3.60				.00342	.00314	109.6
47.25	12.60	2.13				.00382	.00314	121.6
47.60	11.65	3.47				.00400	-	116.5
55.49	13.12	3.61				.00381	.00327	116.5
47.99	14.29	3.05				.00394	.00323	121.9
52.23	13.88	4.81				.00376	.00321	117.1
52.28	16.35	3.60				.00357	.00319	111.9
53.16	14.26	1.47				.00357	.00316	113.0
56.15	14.29	3.75				.00334	.00312	107.0
15	15	15						
3.4	1.8	0.9						
51.68	13.80	3.1	108.2	126.5	87.1			

TABLE B-2. T PROBES -- ENGINE PERFORMANCE AND EMISSION INDICES AT APPRO

Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI	NO_x EI
2	1.320	22	18	12.34	30.34	143	2266	3879	368	190.34	19.41	7.797	4.348
2	1.320	23	23	14.21	30.34	143.3	2275	3889	369	191.34	19.05	5.414	5.176
2	1.309	29	36	26.89	30.14	141.1	2211	3806	420	187.14	18.34	4.904	4.689
2	1.312	31	37	26.89	30.14	142.4	2256	3826	425	189.14	17.67	5.671	4.820
2	1.312	35	65	74.02	29.79	143.1	-	3763	460	187.29	12.94		4.374
2	1.317	40	40	20.59	29.83	143.3	2270	3855	425	187.83	16.39	3.957	4.364
2	1.319	46	38	18.79	29.78	146.7	2241	3861	415	186.78	18.33	2.039	5.524
2	1.314	54	31	10.72	29.92	144.4	2204	3742	400	183.92	18.19	2.611	4.369
2	1.315	63	38	21.54	29.88	150.0	2217	3823	415	185.88	18.37	2.642	5.368
2	1.311	65	58	25.74	30.24	145.9	-	3893	455	190.74	14.11	2.157	5.304
2	1.318	71	58	28.08	30.20	141.1	-	3859	443	189.70	14.12	1.234	5.901
2	1.311	74	75	74.02	29.74	145.7	-	3769	495	184.74	13.70		
2	1.310	79	70	71.45	29.71	142.2	-	3773	480	180.71	13.64	1.806	6.044
2	1.313	82	52	33.27	29.73	144.5	2387	3794	-	183.73	13.93	3.121	5.424
2	1.314	91	53	22.54	29.98	144.8	2205	3785	445	184.98	16.46	2.533	7.264
											15.02	2.745	4.957
N												14	15
S											16	1.90	0.80
X											16.26	3.40	5.20

TABLE B-3. T PROBES -- ENGINE PERFORMANCE AND EMISSION INDICES AT C

Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI	NO_x EI
2	1.744	28	34	26.82	30.05	199.3	4799	8239	570	335.05	4.146	2.706	8.3[illegible]
2	1.740	32	62	71.45	29.72	200.3	4784	8231	640	330.72	3.297	3.344	9.1[illegible]
2	1.754	33	64	71.45	29.11	201.6	4887	8412	637	335.71	2.890	3.806	8.7[illegible]
2	1.730	41	39	20.59	29.74	199.8	4674	8140	592	326.74	4.354	2.181	8.9[illegible]
2	1.734	45	38	18.79	29.70	198	4690	8154	590	329.70	4.471	.671	9.4[illegible]
2	1.731	48	28	10.72	29.83	198.4	4641	8165	550	327.83	4.981	.653	7.4[illegible]
2	1.734	52	28	10.72	29.93	198.4	4661	8165	555	328.83	4.422	.653	7.9[illegible]
2	1.733	59	36	22.54	29.76	210.1	4628	8161	570	328.76	4.314	1.112	8.7[illegible]
2	1.740	66	58	25.74	30.13	200.0	4667	8162	615	332.63	3.401	1.239	9.6[illegible]
2	1.735	70	57	28.08	30.12	200.3	4704	8190	615	331.12	3.250	.985	9.6[illegible]
2	1.746	75	75	71.45	29.64	201.2	4737	8279	685	329.64	2.846	2.724	10.2[illegible]
2	1.742	77	75	71.45	29.63	201.5	4739	8282	675	326.63	2.932	1.665	10.5[illegible]
2	1.739	83	51	33.27	29.62	201.6	4702	8196	-	327.62	3.304	1.605	10.1[illegible]
2	1.739	87	51	33.27	29.84	201.7	4696	8201	-	328.64	3.531	1.330	11.6[illegible]
2	1.738	92	54	22.54	30.89	205.0	4703	8181	620	327.89	3.691	1.079	
2	1.742	96	52	22.54	30.79	198.9	4684	8206	630	331.79	3.482	1.264	9.6[illegible]
N											16		15
S											0.6		1.0[illegible]
X											3.71		9.3[illegible]

CH POWER -- 63 PERCENT RADIUS

CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} x 100}{F/A_M}$ (%)
13.89	1.74	6.28				.00514	.00440	116.8
14.25	1.47	7.19				.00493	.00441	111.8
15.31	2.18	6.04				.00511	.00435	117.5
14.87	2.62	6.16				.00530	.00440	120.5
13.53		5.11				.00584	-	-
14.13	2.04	5.35				.00549	.00440	124.8
15.55	0.98	6.85				.00491	.00424	115.8
14.56	0.97	5.61				.00511	.00424	120.5
15.58	1.27	6.70				.00505	.00411	122.9
14.00	2.09	5.73				-	-	-
14.01	1.19	6.41				-	-	-
15.39	-					-	-	-
14.79	2.59	6.76				-	-	-
13.21	2.46	6.26				.00589	.00459	128.3
15.61	2.00					.00527	.00461	114.3
14.35	2.24	5.51				.00584	.00423	129.6
16	14	14						
0.77	0.58	0.62						
14.56	1.84	6.14	106.2	197.8	98.1			

CRUISE POWER -- 63 PERCENT RADIUS

	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} x 100}{F/A_M}$ (%)
158	3.14	-	11.06				.00804	.00669	120.2
192	3.40	-	10.89				.00801	.00663	120.8
732	3.05	-	10.18				.00880	.00673	130.8
965	3.49	-	11.17				.00767	.00650	118.0
412	3.54	-	11.77				.00748	.00658	113.7
197	3.51	-	10.02				.00768	.00650	118.2
015	3.12	-	10.57				.00768	.00653	117.6
121	3.34	-	11.21				.00752	.00612	122.9
352	3.37	-	10.43				.00813	.00648	125.5
412	3.18	-	10.54				.00850	.00652	130.4
130	3.36	-	10.97				.00861	.00654	131.7
150	3.46	-	11.31				.00804	.00653	123.1
160	3.03	-	11.85				.00835	.00648	128.9
160	3.24	-	13.60				.00755	.00647	116.7
	3.50	-					.00776	.00637	121.8
70	3.23	-	10.87				.00794	.00654	121.4
	16		15						
7	0.17		0.87						
6	3.31		11.10	104.4	-	94.8			

TABLE B-4. T PROBES -- ENGINE PERFORMANCE AND EMISSION INDIC

	Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI
	2	1.919	25	34	24.64	30.03					389.03	4.284	4.249
	2	1.926	27	34	25.74	30.03	213.9	5867	9978	645	390.03	3.080	3.482
	2	1.914	36	66	74.02	29.65	217.9	5437	9860	690	381.65	2.215	3.432
	2	1.918	38	68	76.67	29.63	215.3	5937	9970	700	381.63	2.203	3.569
	2	1.913	42	38	19.67	29.69	215.9	5801	9836	644	381.69	3.086	1.085
	2	1.910	44	38	19.67	29.67	215.2	5812	9842	640	381.67	3.152	.677
	2	1.909	49	28	10.72	29.80	215.5	5762	9845	600	381.80	3.574	.807
	2	1.902	51	28	10.72	29.81	213.1	5707	9744	600	380.81	3.418	.579
	2	1.911	57	34	22.54	29.70	219	5747	9859	625	381.20	3.003	1.320
	2	1.910	58	35	22.54	29.71	225.9	5741	9881	620	381.71	2.960	1.156
	2	1.912	60	36	21.54	29.73	222.8	5746	9874	630	382.73	2.791	.377
	2	1.904	67	58	28.08	30.10	216.9	5748	9804	715	383.10	2.355	.902
	2	1.904	69	57	28.08	30.09	214.7	5720	9720	685	382.09	2.368	.501
	2	1.905	78	72	71.45	29.60	216.5	5741	9825	725	378.60	2.151	.911
	2	1.909	84	51	33.27	29.60	217.6	5742	9817	-	379.60	2.494	1.832
	2	1.908	86	51	33.27	29.61	216.3	5761	9814	-	379.61	2.336	1.123
	2	1.901	93	51	22.54	29.86	216.4	5697	9777	660	376.86	2.547	.896
	2	1.904	95	52	22.54	29.86	217.9	5719	9780	665	379.86	2.444	1.255
	2	1.914	61	36	21.54	29.92	222.6	5713	9877	630	381.72	2.791	.377
N												19	
S												0.56	
$\bar{X}$												2.80	

TABLE B-5. T PROBES -- ENGINE PERFORMANCE AND EMISSION INDICES AT T

	Probe Depth Percent Radius	Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A
	63.2	2	2.041	26	35	25.74	30.01	224.8	6767	11144	690	426.01
	63.2	2	2.051	37	67	76.67	29.63	225.5	6869	11197	740	419.63
	63.2	2	2.049	43	38	19.67	29.64	226.0	6724	11129	688	423.64
	63.2	2	2.051	50	27	10.72	29.79	226.4	6707	11121	645	424.79
	63.2	2	2.049	68	58	28.08	30.08	228.0	6713	11169	710	424.08
	63.2	2	2.048	76	75	71.45	29.57	227.3	6701	11116	780	416.57
	63.2	2	2.048	85	51	33.27	29.59	228.6	6669	11120	-	421.59
	63.2	2	2.050	94	51	22.54	29.85	229.1	6707	11152	705	426.85
	68.3	2	2.043	174	90	141.34	29.48	227.8	6685	11115	795	419.48
	66.6	2	2.050	183	84	79.40	29.49	229.6	6742	11097	750	416.49
	70.2	2	2.032	195	78	61.89	29.85	233.0	6607	11009	790	419.85
	66.6	10	2.020	222	66	74.02	29.70	230.2	6646	11017	720	422.70
	68.5	10	2.065	213	84	111.79	29.59	232.8	6947	11378	750	428.59
	70.2	10	2.018	204	77	74.02	29.80	229.0	6606	10980	750	421.80
N	63.2	2										
S	63.2	2										
$\bar{X}$	63.2	2										

DICES AT MAXIMUM CONTINUOUS POWER -- 63 PERCENT RADIUS

NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} x100}{F/A_M}$ (%)
10.34	3.34	-	13.17				.00867	.00762	113.8
10.36	3.14	-	11.06				.00866	.00762	113.6
10.66	2.36	-	12.43				.00977	.00693	141.0
10.92	2.40	-	12.66				.00939	.00766	122.6
10.38	2.51	-	12.67				.00927	.00746	124.3
10.59	2.56	-	12.92				.00908	.00750	121.1
9.84	2.62	-	12.63				.00829	.00743	111.6
9.60	2.50	-	12.32				.00867	.00744	116.5
10.28	2.34	-	13.02				.00889	.00729	121.9
10.31	2.33	-	12.96				.00870	.00706	123.2
11.37	2.22	-	14.15				.00832	.00716	116.2
12.07	2.33	-	13.11				.00929	.00736	126.2
11.18	2.32	-	12.22				.01004	.00740	135.7
12.72	2.42	-	14.17				.00920	.00737	124.8
	2.31	-					.00915	.00733	124.8
	2.16	-					.00895	.00740	120.9
10.80	2.36	-	12.12				.00935	.00731	127.9
11.65	2.29	-	12.98				.00935	.00729	128.3
11.37	2.22	-	14.15				.00888	.00713	124.5
17	19		17						
0.80	0.30		0.79						
10.85	2.46		12.87	93.2	-	95.6			

T TAKEOFF POWER -- 63, 66, 68, AND 70 PERCENT RADIUS

CO EI	THC EI	NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	F/A CB	F/A Meas.	$\frac{F/A_{CB} x100}{F/A_M}$ (%)
2.564	3.649	11.46	2.14	-	14.05	.00965	.00836	115.4
1.741	4.355	12.27	1.84	-	14.47	.01679	.00846	198.5
2.497	.702	12.60	2.14	-	14.94	.00954	.00826	115.5
2.622	.708	11.85	2.06	-	14.64	.00947	.00823	115.1
1.943	.816	14.52	1.93	-	15.75	.01027	.00818	125.6
1.798	2.023	14.99	2.01	-	16.73	.00995	.00819	121.5
1.958	1.037	15.37	1.85	-	17.56	.00970	.00810	119.8
2.063	.991	13.43	1.95	-	14.91	.01015	.00813	124.8
1.461	-	11.86	1.80	-	14.85	.01014	.00815	124.4
1.518	-	13.73	1.80	-	14.97	.01051	.00816	128.8
1.883	.222	15.67	2.14	-	16.79	.00753	.00788	95.6
3.668	.090	12.57	3.85	-	14.79	.00924	.00802	115.2
1.205	.360	14.23	1.43	-	16.94	.00929	.00829	112.1
1.663	.198	13.28	1.88	-	14.78	.00844	.00801	105.4
8		8	8		8			
0.36		1.50	0.12		1.21			
2.15		13.31	1.98		15.38			

TABLE B-6. T PROBES -- ENGINE PERFORMANCE AND EMISSIO
63, 66, 68, AND 70 PERCENT RADIUS -- 2- AND 10-INCH AX

Probe Depth Percent Radius	Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI
66	2	1.082	188	70	88.10	29.79	78.0	876	1043	250	78.79	48.10	10.02
66	2	1.082	190	76	88.10	29.79	77.3	875	1038	255	79.79	46.27	-
68	2	1.081	170	90	151.09	29.69	77.9	879	1032	290	78.69	78.04	11.41
68	2	1.081	178	90	127.86	29.67	74.9	861	1002	280	77.67	69.71	8.71
70	2	1.080	191	78	59.67	30.06	79.0	875	1058	272	80.06	43.69	-
70	2	1.080	199	78	57.52	30.03	77.0	879	1039	265	80.03		8.40
66	10	1.080	218	68	74.02	29.94	79.5	883	1068	240	80.94	40.86	7.85
66	10	1.080	226	66	82.21	29.94	79.0	884	1063	245	79.94	43.84	10.08
68	10	1.079	209	85	115.62	29.83	79.7	884	1067	265	79.83	32.03	1.17
68	10	1.081	217	85	108.09	29.09	65.9	877	1068	250	78.80	40.21	5.21
70	10	1.077	200	78	79.40	30.04	78.9	881	1059	270	80.04	37.89	-
70	10	1.082	208	77	74.02	30.02	79.0	894	1060	265	81.02	33.26	2.76

TABLE B-7. T PROBES -- ENGINE PERFORMANCE AND EMIS
63, 66, 68, AND 70 PERCENT RADIUS -- 2- AND 10-INCH

Probe Depth Percent Radius	Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI
68	2	1.324	171	92	151.09	29.63	148.4	2265	3892	510	188.63	2.89	0.34
68	2	1.322	177	90	136.70	29.62	148.8	2261	3892	510	187.62	5.215	-
66	2	1.315	189	74	88.10	29.72	146.0	2236	3773	460	183.72	13.31	0.93
70	2	1.317	192	77	61.89	30.00	147.0	2237	3837	485	189.00	11.76	1.17
70	2	1.317	198	78	57.52	29.97	147.0	2209	3841	472	186.97	11.06	.78
66	10	1.315	219	68	74.02	29.87	147.8	2245	3854	445	187.81	13.06	.98
66	10	1.318	225	66.5	85.11	29.85	140.4	2228	3858	445	189.85	11.77	.49
68	10	1.348	210	84	115.62	29.75	155.4	2433	-	500	200.75	6.83	.10
68	10	1.355	216	85	111.79	29.73		2481	-	490	198.73	6.82	.81
70	10	1.312	201	77	76.67	29.97	146.3	2203	3842	-	185.97	9.00	.39
70	10	1.347	207	77	74.02	29.94	154.3	2446	-	505	199.94	11.06	.19

IION INDICES AT IDLE POWER --
AXIAL LOCATIONS

	NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB}\times 100}{F/A_M}$ (%)
2	5.01	50.58	11.33					.00349	.00312	111.8
	2.75	49.97	-	3.04	105.3	103.8	86.6	.00347	.00315	110.2
1	2.07	89.46	15.92	2.51				.00307	.00313	98.1
1	3.12	79.91	12.15	3.54	177.3	128.6	84.7	.00306	.00319	95.9
	2.96	47.59	-	3.03				.00242	.00310	78.1
0	3.63		10.41	3.69	99.7	95.3	94.1	.00197	.00317	62.1
5	1.67	42.58	8.68	1.91				.00382	.00309	123.6
8	4.13	45.13	10.90	4.90	91.8	89.7	95.4	.00347	.00311	111.6
7	2.24	35.96		2.53				.00285	.00308	92.5
1	2.49	45.14	6.91	2.77	84.9	63.3	74.2	.00288	.00370	77.8
	2.22	33.65	-	2.40				.00287	.00310	92.6
6	2.64	41.50	3.37	2.83	78.7	30.9	73.2	.00241	.00314	76.7

IISSION INDICES AT APPROACH POWER --
ICH AXIAL LOCATIONS

NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB}\times 100}{F/A_M}$ (%)
4.97		0.98	5.92				.00481	.00424	113.4
5.14	6.50	-	5.98	-	105.4	95.0	.00465	.00422	110.2
4.74	14.85	1.52	5.40	109.0	163.4	86.3	.00538	.00425	126.6
5.22	13.40	2.10	5.42				.00428	.00423	101.2
-	12.69	1.44	-	95.7	190.3	86.6	.00428	.00417	102.6
4.09	13.96	1.33	4.68				.00507	.00422	120.1
4.74	12.44	0.64	5.64	96.9	105.4	82.4	.00505	.00414	122.0
4.96	8.17	0.24	5.68				.00514	.00438	117.4
	8.22	1.86			112.9	90.7		-	
4.87	10.26	.70	5.26				.00425	.00418	101.7
	12.60	0.35		83.9	56.4	84.0	.00426	.00440	96.8

TABLE B-8. T PROBES-- ENGINE PERFORMANCE AND EMISSION INDIC
63, 66, 68, AND 70 PERCENT RADIUS-- 2- AND 10-INCH AXIAL LOC

Probe Depth Percent Radius	Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI	NO_x EI
68	2	1.752	172	90	141.34	29.53	207.4	4786	8322	705	330.53	1.95	-	7.65
68	2	1.755	176	90	136.70	29.53	205.1	4785	8321	690	330.53	2.49	-	-
66	2	1.756	181	83	79.40	29.55	208.6	4805	8357	662	331.55	2.56	-	10.06
66	2	1.759	185	84	79.40	29.51	206.6	4825	8368	655	379.51	2.58	-	9.98
70	2	1.746	193	78	61.89	29.90	208.0	4744	8278	660	333.90	2.93	.68	11.07
70	2	1.750	197	78	61.89	29.89	196.0	4748	8311	660	335.89	3.16	.27	10.76
70	10	1.747	202	77	76.67	29.87	209.6	4813	8368	-	308.87	2.58	.25	9.11
70	10	1.732	206	77	74.02	29.84	203.2	4732	8226	670	331.84	4.52	-	8.80
68	10	1.740	211	85	115.62	29.64	208.7	4765	8290	650	332.64	1.87	.33	9.41
68	10	1.740	215	85	111.79	29.65	204.3	4756	8283	650	332.65	1.94	.33	9.66
66	10	1.746	220	66	74.02	29.95	208.3	4783	8363	620	334.75	2.77	.22	9.10
66	10	1.750	224	68	85.11	29.95	206.9	4764	8352	624	335.75	2.85	-	9.36

TABLE B-9. T PROBES -- ENGINE PERFORMANCE AND EMISSION INDICES
63, 66, 68, AND 70 PERCENT RADIUS -- 2- AND 10-INCH AXIAL LOCATI

Probe Depth Percent Radius	Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI	N E
68	2	1.919	173	90	141.34	29.50	216.6	5831	9925	750	379.50	1.903	-	1
68	2	1.919	175	90	136.70	29.50	219.0	5846	9924	745	378.50	1.798	-	1
66	2	1.918	182	83	79.40	29.52	218.7	5806	9874	710	381.52	1.808	-	1
66	2	1.919	184	84	79.40	29.50	218.3	5827	9881	710	379.50	1.909	-	1
70	2	1.917	194	78	61.89	29.87	203.0	5821	9939	715	386.87	2.276	.35	1
70	2	1.921	196	78	61.89	29.87	220.0	5800	9939	712	388.87	2.276	.24	1
70	10	1.914	203	77	76.67	29.81	221.3	5846	9960	-	389.81	1.871	.22	11
70	10	1.976	205	77	74.02	29.83	220.5	5852	9957	715	384.83	1.300	-	11
68	10	1.905	212	83	115.62	29.61	219.9	5825	9379	710	382.61	1.562	.80	4
68	10	1.908	214	84	111.79	29.62	220.2	5837	9931	705	380.62	1.507	.30	11
66	10	1.912	221	65	74.02	29.73	222.4	5878	9988	690	389.73	3.252	.09	11
66	10	1.915	223	67	74.02	29.72	222.9	5900	9990	690	387.72	4.766	.09	11

ICES AT CRUISE POWER --
OCATIONS

NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} \times 100}{F/A_M}$ (%)
.65	2.67	-	8.90				.00900	.00641	140.4
-	3.40	-		95.7	-	76.0	.00745	.00648	115.0
.06	3.27	-	10.40				.00843	.00640	131.7
.98	3.33	-	10.24	104.4	-	88.1	.00802	.00649	123.6
.07	3.56	-	11.32				.00613	.00634	96.7
.76	3.84	-	11.00	116.7	-	95.3	.00613	.00673	91.1
.11	3.11	-	9.77				.00658	.00638	103.1
.80		-	9.38	98.1	-	81.7	.00659	.00647	101.9
.41	2.43	-	10.58				.00744	.00634	117.4
.66	2.53	-	10.75	78.2	-	91.0	.00745	.00647	115.1
.10	2.99	-	10.55				.00747	.00638	117.1
.36	3.13	-	10.98	96.5	-	91.9	.00726	.00640	113.4

ES AT MAXIMUM CONTINUOUS POWER --
ATIONS

NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} \times 100}{F/A_M}$ (%)
10.59	2.51	-	12.76				.00877	.00748	117.2
10.58	2.37	-	12.59	92.4	-	94.1	.00878	.00742	118.3
12.16	2.25	-	12.93				.00930	.00737	127.0
12.16	2.39	-	12.85	87.9	-	95.8	.00936	.00741	126.3
13.01	2.71	-	13.61				.00707	.00797	88.7
13.01	2.54	-	14.22	99.2	-	103.3	.00707	.00732	96.6
11.72	2.21	-	12.84				.00751	.00734	102.3
11.92	1.53	-	11.92	70.8	-	92.0	.00704	.00737	95.5
4.593	1.94	-					.00837	.00736	113.7
11.73	1.89	-	13.53	72.3	-	100.5	.00837	.00736	113.7
11.19	3.44	-	13.14				.00924	.00734	125.9
11.06		-	12.82	130.3	-	96.4	.00850	.00735	115.6

2

APPENDIX C

DIAMOND PROBE - ENGINE PERFORMANCE AND EMISSION DATA BASE

TABLE C-1 DIAMOND PROBE -- ENGINE PERFORMANCE AND EM
2-,7-, AND 10-INCH AXIAL LOCATIONS

Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI	NO_x EI
2	1.075	99	74	74.02	29.87	77.5	894	1014	270	77.87	44.60	7.40	2.74
2	1.082	107	71	76.67	29.83	77.5	886	995	265	78.83	50.89	-	-
2	1.080	108	72	64.17	29.91	75.0	888	1043	262	79.91	43.27	10.64	1.97
2	1.084	116	69	66.53	29.88	77.5	887	1045	250	79.88	50.45	11.62	2.61
2	1.077	117	84	88.1	29.79	76.6	885	1017	287	79.79	44.55	12.05	1.97
2	1.077	125	83	97.63	29.76	77.9	886	1019	280	78.76	46.07	7.85	2.39
N													
$\bar{X}$													
S													
7	1.080	126	77	85.11	29.81	78.6	890	1016	280	79.81	45.67	9.63	2.12
7	1.081	134	81	64.17	29.77	77.4	880	1007	275	78.77	43.67	8.45	2.12
7	1.085	135	70	49.51	29.96	79.5	896	1061	252	80.96	42.36	8.85	2.57
7	1.084	142	70	47.66	29.54	79.1	892	1042	250	79.54	47.81	11.48	2.56
7	1.082	143	70	68.95	30.06	-	877	1038	262	81.06	45.24	6.73	2.32
7	1.083	151	70	66.53	30.05	78.8	897	1058	260	81.05	45.36		2.51
N													
$\bar{X}$													
S													
10	1.080	152	74	74.02	30.18	78.6	891	1054	272	81.18	43.38	6.37	2.51
10	1.083	160	71	7.45	30.16	78.9	890	1055	270	81.16	43.40	6.00	2.51
$\bar{X}$													

MISSION INDICES AT IDLE POWER --

CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} \times 100}{F/A_M}$ (%)
47.74	8.78	2.99				.00291	.00320	1
53.76	-					.00411	.00318	129.2
45.91	12.29	2.13				.00486	.00329	146.2
52.82	12.99	2.90				.00488	.00318	148.3
49.80	15.81	2.09				.00485	.00321	151.0
51.28	10.19	2.61				.00468	.00315	148.6
6	5	5						
50.22	12.01	2.54	105.2	110.1	71.1			
3.01	2.70	.42						
49.55	11.74	2.34				.00450	.00315	142.8
48.19	10.81	2.15				.00452	.00316	143.0
44.55	10.00	2.71				.00434	.00313	138.7
50.28	12.98	2.68				.00436	.00313	139.3
47.57	-	2.58				.00446	-	
47.70	-	2.77				.00445	.00316	140.8
6	4	6						
47.97	11.38	2.54	100.5	104.3	71.1			
1.99	1.28	.24						
46.44	7.53	2.75				.00445	.00313	141.3
45.46	7.08	2.73	96.2	66.9	76.8	.00445	.00313	141.3
45.95	7.30	2.74						

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TABLE C-2 DIAMOND PROBE -- ENGINE PERFORMANCE AND
2- 7-, AND 10-INCH AXIAL LOCATIONS

Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI
2	1.319	100	72	74.02	29.80	145	-	3741	480	184.80	12.11	1.65
2	1.326	106	72	76.67	29.76	146.3	-	3767	480	186.76	14.12	1.18
2	1.325	109	74	64.17	29.84	146.5	2251	3756	470	184.84	14.09	.74
2	1.329	115	70	66.53	29.82	146.9	2237	3757	510	185.82	14.65	1.44
2	1.336	118	84	88.10	29.72	147.1	2330	3824	508	189.72	11.84	.76
2	1.317	124	84	94.35	29.69	142.8	2322	3828	508	-	10.71	.50
7	1.333	127	80	85.11	29.75	150.0	2312	3834	495	190.75	11.00	.412
7	1.330	133	81	71.45	29.70	148.5	2325	3846	500	189.70	10.76	.401
7	1.328	136	69	47.66	29.88	149.6	2314	3841	468	189.88	13.26	.8423
7	1.331	141	69	47.66	29.88	149.4	2311	3841	455	191.88	12.85	.8167
7	1.327	144	69.5	68.95	30.00	150.5	2306	3837	478	193.00	12.39	.8208
7	1.327	150	70	66.52	29.99	149.6	2291	3839	473	192.99	12.02	.7962
10	1.327	153	74	74.02	30.10	150.9	2304	3845	490	194.10	12.39	.5480
10	1.329	159	74	71.45	30.09	150.4	2314	3876	490	194.09	11.67	.8476

TABLE C-3 DIAMOND PROBE -- ENGINE PERFORMANC
2- 7-, AND 10-INCH AXIAL LOCATIONS

Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI
2	1.778	101	73	74.02	29.70	202.1	4943	8242	670	329.70	4.35	.97
2	1.789	105	71	76.67	29.67	201.6	4911	8190	660	336.67	3.03	.31
2	1.807	110	74	68.95	29.75	207.9	4964	8329	660	338.75	2.82	.48
2	1.808	114	71	68.95	29.92	204.1	4951	8338	680	338.72	3.07	1.11
2	1.804	119	82	88.10	29.62	205.9	5012	8236	683	337.62	2.89	.35
2	1.874	123	83	94.35	29.60	209.6	5092	8222	700	339.60	2.67	.08
7	1.796	128	80	85.11	29.64	213.0	5083	8333	690	345.64	3.39	.17
7	1.798	132	81	71.45	29.59	208.9	5130	8345	705	345.59	2.14	.17
7	1.799	140	69	47.66	29.77	208.8	5080	8361	650	349.77	2.85	.18
7	1.752	145	70	68.95	29.92	209.2	4782	7949	696	336.92	3.06	.18
7	1.752	149	70	66.53	29.91	206.1	4782	7950	650	335.91	2.95	.18
10	1.745	154	74	76.67	30.01	209.4	4762	7925	670	338.01	2.95	.37
10	1.747	158	74	71.45	30.00	204.6	4793	7927	658	338.00	3.03	.38

ND EMISSION INDICES AT APPROACH POWER--

NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} \times 100}{F/A_M}$ (%)
5.413	13.32	2.53	6.01				-	-	
6.803	15.53	1.82	7.61				-	-	
5.66	15.72	1.21	6.03				.00678	.00427	158.8
5.048	15.88	2.07	5.57				.00697	.00423	164.8
5.575	14.16	1.70	5.91				.00659	.00440	149.8
5.102	12.81	1.13	5.50	106.9	187.1	97.4	.00658	.00452	145.6
5.256	12.80	0.81	5.69				.00608	.00428	142.1
4.867	12.61	0.82	5.04				.00624	.00435	143.4
5.637	14.27	1.17	5.96				.00595	.00430	138.4
5.205	13.83	1.14	5.50				.00614	.00430	142.8
5.232	13.39	1.16	5.83				.00611	.00426	143.4
5.074	13.03	1.14	5.60	97.8	111.8	89.4	.00630	.00425	148.2
5.501	13.82	0.89	6.02				.00610	.00424	143.9
5.672	13.02	1.38	6.17	98.5	121.5	97.4	.00591	.00427	138.4

ANCE AND EMISSION INDICES AT CRUISE POWER--

NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} \times 100}{F/A_M}$ (%)
9.75	5.03	-	10.69				.01036	.00679	152.6
10.51	3.44	-	11.78				.01053	.00671	155.5
10.57	3.30	-	11.35				.01032	.00663	155.7
9.90	3.48	-	10.87				.01102	.00674	163.5
10.75	3.66	-	11.46				.00939	.00676	138.9
10.48	3.42	-	11.28	117.3	-	96.0	.00979	.00675	145.0
10.23	4.21	-	10.97				.00940	.00663	141.8
9.96	2.68	-	10.22				.00966	.00682	141.6
11.21	3.16	-	11.80				.00929	.00676	137.4
9.87	3.44	-	10.92				.00892	.00635	140.5
10.05	3.32	-	11.05	106.0	-	92.3	.00893	.00645	138.4
10.07	3.45	-	11.04				.00891	.00632	141.0
10.33	3.95	-	11.16	116.7	-	94.8	.00869	.00651	133.5

TABLE C-4 DIAMOND PROBE -- ENGINE PERFORMANCE AND EMI
CONTINUOUS POWER--2-, 7-, AND 10-INCH AXIAL LOCATIONS

Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI
2	1.958	102	72	74.02	29.65	213.5	5984	9605	715	381.65	2.20	1.02
2	1.958	104	72	74.02	29.65	213.7	5777	9554	710	380.65	2.24	0.41
2	1.989	111	73	68.95	29.73	216.2	6105	9833	715	391.73	2.36	.56
2	1.987	113	72	68.95	29.70	218.2	6087	9843	705	390.70	2.26	.06
2	1.994	120	83	94.35	29.59	218.4	6195	9885	744	389.59	1.92	.15
2	1.998	122	84	94.35	29.57	217.1	6192	9871	750	389.57	2.00	.07
7	1.960	129	80	71.45	29.60	223.5	6185	9806	735	397.60	1.66	.15
7	1.967	131	81	71.45	29.58	224.7	6215	9854	750	399.58	1.59	.14
7	1.971	137	69	47.66	29.74	225.5	6257	9873	705	401.74	2.28	.24
7	1.972	139	70	47.66	29.74	225.3	6228	9876	706	402.74	2.28	.24
7	1.917	146	70	66.53	29.88	220.7	5854	9428	705	389.88	2.22	.16
7	1.917	148	70	66.53	29.88	220.8	5872	9428	705	388.88	2.12	.16
10	1.917	155	74	76.67	29.98	221.4	5867	9449	726	391.98	2.16	.25
10	1.917	157	74	71.45	29.98	220.1	5878	9448	728	391.88	2.16	.33

TABLE C-5 DIAMOND PROBE -- ENGINE PERFORMANCE AND EMIS
2-, 7-, AND 10-INCH AXIAL LOCATIONS

Probe Axial Pos. Inch	EPR	Run No.	t_2 °F	Spec. H Grains H_2O lb/Air	P_2 in. Hg. A	Air-Flow lb/Sec.	Fuel Flow lb/Hr.	Thrust lb	t_3 °F	P_3 in. Hg. A	CO EI	THC EI
2	2.049	103	72	70.02	29.64	220.4	6580	10303	745	406.64	1.98	.82
2	2.115	112	72	68.95	29.68	226.1	6927	10921	745	427.68	2.05	.25
2	2.109	121	84	94.35	29.57	226.8	7019	10865	783	424.57	1.69	.13
7	2.069	130	82	71.45	29.57	233.5	6986	10810	790	431.57	1.44	.07
7	2.097	138	69	47.66	29.73	236.2	7169	11051	750	444.73	2.05	.21
7	2.035	147	70	66.53	29.86	234.3	6688	10452	745	424.86	1.90	.15
10	2.025	156	74	76.67	29.96	231.4	6710	10416	760	424.96	1.81	.23

EMISSION INDICES AT MAXIMUM
NS

NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO EI Percent Traverse Avg.	THC EI Percent Traverse Avg.	NO_x EI Percent Traverse Avg.	F/A CB	F/A Meas.	$\frac{F/A_{CB} \times 100}{F/A_M}$ (%)
11.86	2.48	-	13.31				.01151	.00779	147.8
11.29	2.53	-	12.76				.01210	.00751	161.1
11.84	2.69	-	13.02				.01194	.00784	152.3
11.63	2.55	-	12.87				.01244	.00775	160.5
12.65	2.39	-	14.00				.01117	.00738	141.8
12.65	2.52	-	13.92	95.7	-	98.9	.01117	.00792	141.0
13.12	2.01	-	13.91				.01077	.00769	140.1
12.58	1.94	-	13.25				.01123	.00768	146.2
13.93	2.50	-	14.84				.01036	.00771	134.4
13.62	2.53	-	14.42				.01036	.00768	134.9
12.29	2.46	-	13.69				.01018	.00737	138.1
12.29	2.36	-	13.69	87.[illegible]	-	103.8	.01018	.00739	137.8
12.87	2.49	-	14.36				.00997	.00736	135.5
12.53	2.49	-	13.79	94.3	-	103.8	.00998	.00742	134.5

MISSION INDICES AT TAKEOFF POWER--

NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	F/A CB	F/A Meas.	$\frac{F/A_{CB} \times 100}{F/A_M}$ (%)
12.81	2.17	-	14.62	.01229	.00829	148.3
13.38	2.25	-	15.04	.01322	.00851	155.3
13.90	-		15.78	.01214	.00860	141.2
14.15	1.69	-	15.25	.01169	.00831	140.7
15.05	2.20	-	16.24	.01153	.00843	136.8
13.73	2.06	-	15.51	.01087	.00793	137.1
14.50	2.02	-	16.50	.01085	.00805	134.8

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